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SEPTEMBER, 1894.

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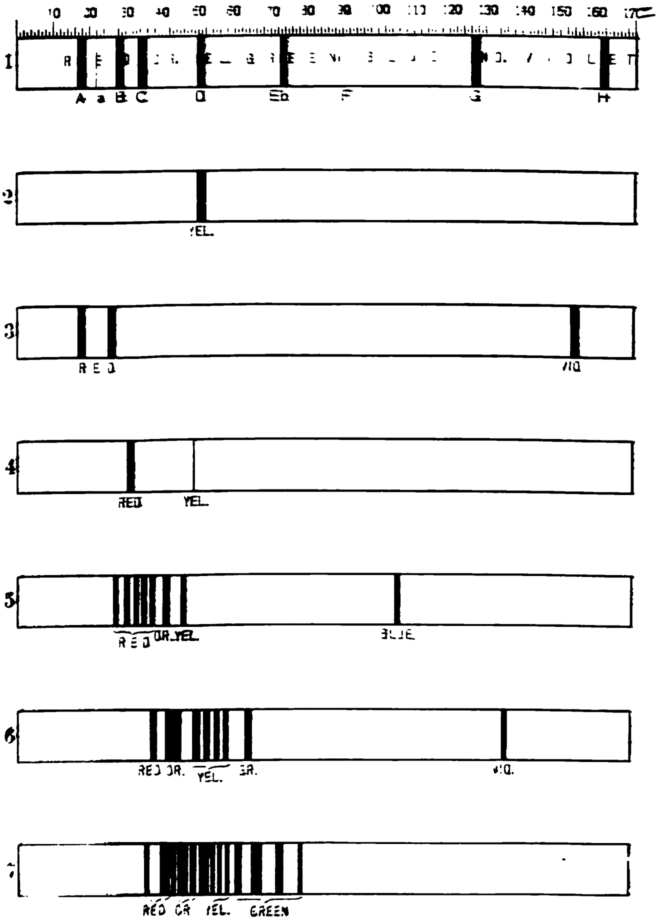
SPECTRA



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4.LITHIUM (RARE). 5.STRONTIUM. 6.CALCIUM 7.BARIUM.

ELEMENTS OF PHYSICS.

CHAPTER I.

INTRODUCTION.

ANYTHING which occupies space is **matter.**

Exp. 1. — Invert a tumbler and press it downward into a dish of water. The water does not enter and fill the tumbler, because the space is already occupied by air.

Exp. 2. — Float a short piece of candle on cork in water. Light candle and cover with inverted tumbler. What very soon happens ?

Matter may exist in an **invisible** state, but as all visible matter is not the same kind of matter, so all invisible matter is not the same kind of matter. The tumbler full of invisible matter in which the candle at first burned was certainly very different from the invisible matter in which at last the candle would not burn. Students who have studied chemistry will remember that most gases are invisible.

A **substance** is some particular kind of matter; as, salt, iron, marble.

A **body** is some definite portion of matter; as, a ball, a table, a stone.

A **Force** is a **push** or a **pull** exerted upon anything. The force exerted by animals is called muscular force.

Examples of other forces will appear as we study the various causes of the "pushes" and "pulls" observed in nature.

Work is overcoming resistance.

Energy is the ability to do work or to overcome resistance.

Physics treats of matter and force, or of matter as a medium for the operation of energy. In the restricted sense of school text-books, Physics does not treat of matter as related to life (biology) nor of changes in matter which alter its atomic condition; that is, which make the particular kind of matter a different kind of matter, or make out of it different substances (chemistry). It does, however, take note of the force or energy accompanying such changes. It leaves to mineralogy the study of minerals; to geology, the study of the earth's structure and physical history; and to astronomy, the study of matter considered as related to that community called "heavenly bodies," of which the earth as a planet is one. Other subjects upon which school text-books are written might be mentioned. Indeed, all related "studies" are continuously running beyond their own boundaries and trespassing upon one another's territory.

CHAPTER II.

GENERAL PROPERTIES OF MATTER.

. 3. — Measure the length, breadth, and thick- a piece of wood of right-angled cross section, ıd its volume (space occupied) with reference e standard unit, as the centimeter or inch.

•. 4. — Measure with a pair of calipers the diam- a cylindrical solid (as piece of round molding), ıd its volume. [Appendix, Section II.]

›. 5. — Measure the diameter of a sphere (large ; or celluloid ball) with calipers, and find its e.

›. 6. — Measure with calipers the inside and ; diameters of a hollow tube of iron or brass. re also the length, and find the cubic centi- ; of iron or brass in it.

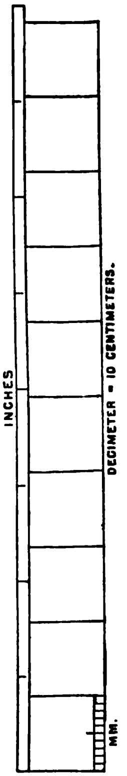

Fig. 1.

tension is that property of matter by ı it occupies space. The space oc- d by a body is called its volume. nsion has three dimensions — length, lth, and thickness. Without these there can be no extension in the in which we speak of it as a prop- of matter. Mere surface includes no ɜr. [To find the extension of an "irreg- ' solid, see Exp. 74.]

P. 7. — Over a lighted candle, burning without , hold a cold, wide-mouthed glass bottle. What ı observe gathering upon the cold bottle ?

ELEMENTS OF PHYSICS

FOR USE IN

SECONDARY SCHOOLS

BY

S. P. MEADS

OAKLAND HIGH SCHOOL, OAKLAND, CAL.

SILVER, BURDETT AND COMPANY
NEW YORK . . . BOSTON . . . CHICAGO
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CHAPTER III.

SPECIFIC PROPERTIES OF MATTER.

The most important of the specific properties of matter are malleability, brittleness, hardness, ductility, tenacity, elasticity and viscosity. To these may be added cohesion and adhesion, which are better studied as forces. Specific properties belong to *some* matter only but not to all matter. Many of them are not properly said to be possessed by liquids and gases at all. If, however, we consider some of these properties in minute and scarcely perceptible degrees, we might class them as general properties. The above list could be almost indefinitely extended.

Exp. 17. Place upon an anvil or other firm support small pieces of lead, antimony, tin, cast-iron, copper, and bismuth, successively, and hammer each.

Malleability is that property of some matter which enables it be hammered or rolled into sheets.

Brittleness is that property of some matter which causes it to be easily broken by a blow. Brittle bodies also break when suddenly bent beyond the "limit of elasticity." [See elasticity.]

Exp. 18. Wind a fine piece of copper wire about a nail and set two inches of the free end into a small vise with moderate firmness. Pull the wire out and repeat until the end is perceptibly lengthened.

Exp. 19.—Raise the center of a short piece of fine glass tubing to the red heat and suddenly draw out into a thread.

Ductility is that property of some matter which renders it capable of being drawn out into wire.

Unless otherwise stated, a ductile substance is one that can be drawn out *cold;* as glass is not ductile, but red-hot glass is ductile.

Exp. 20. — Take in couplets a common nail and a piece of glass, a piece of marble and a piece of quartz, pieces of any two kinds of mineral, and find out which will scratch the other.

Hardness is that property of some matter by which it resists scratching.

In the science of mineralogy hardness is of great importance in classification. It is expressed in degrees from one to ten, according to the following scale: 1. Talc. 2. Gypsum. 3. Calcite. 4. Fluor-Spar. 5. Apatite. 6. Feldspar. 7. Quartz. 8. Topaz. 9. Corundum. 10. Diamond. By comparison with this standard the hardness of any mineral may be ascertained. The color of the scratch upon a mineral is called its *streak.*

Exp. 21. — Break by pulling a very small copper wire. Do the same with a steel wire *of equal size* (determined by wire gauge). Hold one end by vise and fasten the other to a spring balance, observing carefully the force (estimated in lb. or kg.) needed to break each.

Tenacity is that property of some matter which enables it to resist a force tending to *pull* it apart.

Ductile bodies must be tenacious, but tenacious bodies may or may not be ductile. The tenacity of a substance is increased by drawing it into wire. Wire cables are stronger than rods of the same diameter. The weight which a wire sustains, that is, the pulling force, estimated in gravity units (lb. or kg.), which it is resisting, measures its *tension.*

Exp. 22. — Compress a piece of soft rubber. Expand it moderately. Twist it moderately.

Elasticity is that property by which a body tends to return to the same **form** or **volume,** when that form or volume has been changed by the application of some external force. Elasticity may be (1) *of form* or (2) *of volume*. Gases have no elasticity of form, neither have liquids, — except so far as globules have a tendency to remain such [see surface tension], — but many solids have both elasticity of form and of volume in a high degree. Elasticity is said to be

(1) of Compression
(2) of Expansion
(3) of Torsion

according as the body is compressed, expanded, or twisted respectively *before* it returns. Elasticity of Flexure includes compression on the concave side, and expansion on the convex side. Elasticity of Stretch includes linear expansion, and compression of the sectional-area disk.

Exp. 23. — Upon a small marble slab spread a thin coat of oil, and place an ivory ball upon it. Drop the ball from a small height. Double the height and drop again. Notice the size of the three spots made upon the marble and the energy of the rebound after balls have been *compressed* by collision with the marble. Repeat the experiment with balls made of other material, as wood, lead, agate.

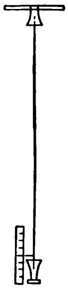
Fig. 8.

Exp. 24. — Strike a steel anvil with a steel hammer and observe the prompt action of elasticity.

Exp. 25. — Support a small, straight steel wire, about three meters long, from a firmly suspended vise, Fig. 8. Tie near its lower end a stiff bristle, wax contact and leave projecting end as pointer. Mark upon a fixed card the position of pointer. Attach a small vise of known weight to end of wire, and mark card again. Double the weight by adding sand-bag of same weight as vise, and mark again. Add two more sand-bags, and quadruple the weight. Remove weights in inverse order and observe pointer. (*b*) Measure carefully the graduations upon an ordinary spring balance. What force must be applied to produce twice the strain on spring? To produce three times the strain? Two and three-fourths times?

Exp. 26. — Take a steel wire two decimeters long, and with pincers turn at right angles a centimeter's length at one end. Fasten the other end in vise, and, twisting, observe the return force at different degrees. Do the same with wires of copper, brass, etc.

Exp. 27. — Nearly close by fusion one end of a glass tube, and, boring hole in rubber cork, pass the closed end (upward) through it, and insert in flask (Fig. 9) containing a little clean water, so that the end of tube shall be beneath the water. Blow gently into the tube and remove mouth. Blow violently into tube. [Liquids are almost incompressible, as may be shown by filling the bottle *full* of water and trying to blow air in.]

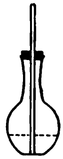

Fig. 9.

Exp. 28. — Fasten short strips of sheet brass, of steel, copper, and lead successively into a vise. First bend a little, and afterward a great deal, and observe the return.

Exp. 29. — Stretch a small rubber band until it nearly breaks, and, measuring, see if it returns completely. Compare the length of an old rubber band with one just from the box.

Elasticity, like gravitation, is oftener treated as a **force.** This may be developed by *compression*, *expansion*, or *torsion*. It is the force with which a body resists an attempt to change its form or volume by the application of an external force. The force applied to change form or volume is called *stress*, and the change produced is called *strain*. When a certain degree of strain is reached, the body does not return *completely*, if the stress is removed. This point is called the "*limit of elasticity*."

Elasticity is developed in gases only by *compression*. They are very compressible, but liquids can be compressed so little that for a long time they were thought to be incompressible. [Exp. 50, *b*.] Gases and Liquids, so long as they remain such, have no "limit" to their elasticity of compression, but if compressed, when the compressing force is removed, *restitution* both of volume and of force is complete. On this account liquids and gases were called by the old physicists "perfectly elastic," but in the "*force*" sense of the word nothing is perfectly elastic. We still speak of liquids and gases as perfectly elastic, but only in this sense that ***restitution*** **is perfect.** Liquids and gases become more highly elastic as they become more compressed. Great extensibility or flexibility (limit of elasticity large) on the part of solids must not be confounded with great elasticity, though in a general commercial, literary, and even physiological sense this is done. Glass is highly elastic, though its limit of elasticity is soon reached. Rubber is very extensible and flexible, but not "highly elastic," the force with which it returns being moderate. A long-continued strain produces a permanent change of form ("set") even when the ordinary "limit of elasticity" has not been reached. Bodies possessing elasticity in a low degree, as lead and putty, are spoken of *relatively* as "inelastic."

EXP. 30. — Try to bend a stick of sealing-wax. It breaks. Tie a moderately heavy weight to the center of another stick, and support each end. Observe what happens in a day or two.

Viscosity, as applied to solids, is that property of some solids by reason of which they may be slowly, but not rapidly, changed in form without fracture by a stress. Ice is viscous, as is proved by the "flowing" of glaciers around turns in their channels. **Viscosity,** as applied to liquids, is that property (due to cohesion and internal friction) which makes a liquid, as cold molasses, flow slowly. These liquids, being sticky (adhesive), are also called "*viscid.*"

EXP. 31. — Cut a lead bullet into two parts. Place the clean, smooth surfaces together. They do not cohere. Press the surfaces together firmly with twisting motion.

EXP. 32. — Press two pieces of clean glass together firmly and raise the upper piece.

EXP. 33. — Drop 20 drops of water slowly into a graduate (or narrow test-tube). Into another drop twenty drops of glycerine. Compare volume of each.

EXP. 34. — Dip a piece of glass into water and remove it. Water adheres to the glass. Dip clean glass into pure mercury and remove.

That force which holds molecules together in apparent contact is called **Cohesion** if the action is between *like* molecules, and **Adhesion** if the action is between *unlike* molecules.

No molecules are in *actual* contact (see heat). Variations in the cohesive force give to bodies of like molecules the specific properties above mentioned, and determines whether the bodies are to be solid, liquid, or gaseous. In general, variation in the cohesive force causes the molecules to move upon each other with difficulty in solids and readily in liquids. In gases the cohesion is "over-balanced" by other forces (heat, inertia of motion), the molecules having an *apparent* repulsion for each other, so that gaseous bodies tend to expand indefinitely. Cohesion and adhesion act only at exceedingly minute distances.

EXP. 35. — Pour out into two beakers a little water, and into a third a globule of mercury. Put a small piece of salt into the first, and a clean shaving of zinc into the second and third. [Do not return mercury containing dissolved zinc to bottle, but pour into bottle of impure mercury].

EXP. 36. — Pour water upon mercury and remove by blotting-paper.

EXP. 37. — Borrow from chemical laboratory hydrogen sulphide generator. Pour a little distilled water into bottom of deep bottle. Carefully pass through it a few bubbles of the gas, and, closing mouth of bottle, shake thoroughly. Pour the water into a bottle that it will fill, and put in stopple. Return generator, and after odor of escaped gas has gone examine water. That it has dissolved some of the gas is evident. [One pupil may perform this in presence of class, all examining water]. [See Chemistry, EXPS. 61, 69, 75, etc., and for absorption of gases by solids, Chemistry, EXPS. 47 and Appendix, EXP. 2.]

Solubility and **Absorption.** A solid dissolves in a liquid when the adhesion between the molecules of the solid and the molecules of the liquid is greater than the cohesion between the molecules of the solid. Dissolving a solid in a liquid or absorbing a liquid by a solid is overcoming cohesion by adhesion. A solid is insoluble in a liquid when the cohesion between its molecules is greater than the adhesion between its molecules and those of the liquid. An insoluble solid is not even *wet* by a liquid the cohesion of whose molecules is greater than the adhesion between the molecules of the solid and liquid. A solid is wet by a liquid whenever adhesion is stronger than the cohesion either of the liquid or of the solid, and such a solid, if visibly porous, absorbs the liquid. When the solid is drawn into the pores of the liquid, we call it solution, but when a liquid or a gas is drawn into the pores of a solid, we call it absorption. A liquid containing all of a solid that it will dissolve is called a *saturated* solution.

Heat usually weakens cohesion more than adhesion, so that as a rule hot liquids dissolve more of a solid, and dissolve it more rapidly, than cold ones do. A ten per cent solution contains ten parts by weight to ninety of the dissolving liquid. That foul gases usually dissolve quite readily in water is an important hygienic fact. Solids often undergo positive *chemical changes* before or in dissolving. About such solutions *chemistry* tells us. Some authors claim that there is a more or less decided chemical action whenever we make a solution of a solid in a liquid.

Exp. 38. — Stand into a dish of water two clean glass tubes, one fine, the other coarser. Place similar tubes in a vessel of mercury. Examine carefully. Draw vertical section through tubes showing liquid surface plainly.

The action of cohesion and adhesion where the surface of a liquid approaches a solid, especially the action of these forces in fine *tubes* and visible pores, is called **capillarity.** When the liquid wets the solid, the liquid is drawn upward in capillary tubes and pores and the surface is concave upward. When the liquid does not wet the solid, it is depressed or *apparently* repelled, and the surface is convex upward in the tubes. The same is true on the margin where surfaces of liquids in large tubes or receivers touch solids. A tube is not "capillary" unless the action reaches perceptibly the center of it. The finer the tube the greater the effect of this action.

A rough explanation may be given from section in Fig. 10. Let *AD* be the surface molecules along any level line of water or mercury in the glass tube as these molecules would lie if uninfluenced by capillarity. The molecule *A*, if water, is drawn against the glass and obliquely upward by adhesion more strongly than it is drawn away from the glass and downward by cohesion, consequently it moves upward towards *B* and carries other molecules with it by the force of cohesion. The surface takes the shape *M*, and if the tube is capillary the center falls below the line *AD*. If *A* is a molecule of mercury, it is drawn inward and downward by cohesion more strongly than it is drawn in opposite directions by adhesion, therefore it moves downward (and inward), and the surface takes the shape *W*. [See surface tension below].

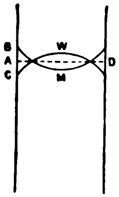

Fig. 10.

Examples of capillarity are numerous: lamp wicks absorbing oil, towels wet at one end, dry pine plugs driven into drill-holes and wet for the purpose of splitting granite blocks, etc. Water will not flow from a tube by capillary action, but rises and evaporates at surface. Plowing and harrowing break up the fine pores into coarser ones, and, reducing the capillary action, make the ground retain better its moisture near the surface.

Exp. 39. — Powder blue litmus and dissolve in water. Filter and let filtrate fall into a deep, wide test-tube. By means of thistle tube (long fine-tubed funnel) let a few drops of strong sulphuric acid sink to the bottom of the test-tube. Let liquids stand quietly and watch their diffusion. ["Acids turn blue litmus red."]

Exp. 40. — Fill a small bottle (mouth upward) with carbon dioxide from generator borrowed from chemical laboratory. Test with slender lighted taper. The flame is extinguished. Leave bottle unstopped and test a half-hour later. Air is found in the bottle, the carbon dioxide having passed out by diffusion. [Chemistry, Exps. 51, 52, also 29, and comments.]

Diffusion of Liquids depends partly upon adhesion and partly upon molecular motion, while **Diffusion of Gases** depends principally upon molecular motion, the adhesive force being very minute. A liquid mixed with water is said to be *diluted* with water instead of dissolved in water. Some liquids will not, but all gases will, diffuse into one another. If undisturbed by outside forces, heavy liquids do not *equally* mix with light ones, nor heavy gases equally with light ones. [See gravity battery and Chemistry, page 68, "old wells."]

Exp. 41. — Tie a piece of parchment paper (or of animal membrane) over the end of a lamp chimney. Pour into it about one inch deep a strong solution of common salt mixed with solution of gum arabic, and immerse about an inch deep in a little distilled water in beaker. Leave over night. Remove chimney and test water in beaker by taste for salt and gum. Much salt and little gum has passed through.

The diffusion of liquids through membranes is called **osmose** (the flow towards the increased volume *end-osmose* and from the increased volume *ex-osmose*). Crystallized substances ("crystalloids") pass through membranes more readily than gummy substances ("colloids"). Separating substances by osmose is called **dialysis** and the apparatus used a *dialyzer*. Chemists separate crystalline poisons from the mucus of the stomach by dialysis before testing for them. Sap circulates through the membranes of lining cells by osmose rather than by capillarity.

Exp. 42. — Place a small globule of mercury upon a piece of glass and notice with what force it resists flattening (or a change of *form*). (*b*) Blow a small soap bubble and let the air return through pipe.

Surface Tension is a tension or pulling force due to the unbalanced action of cohesion at the surface of a liquid. Let dots *A*, *B*, and *C* represent three type molecules in a globule of a liquid (Fig. 11). A line is drawn about each at the limit to which the force of cohesion extends. It is manifest that not only *A* at the center, but also *B*, is drawn equally in all directions *by cohesion*. This is not the case with *C*, which is drawn in all directions sidewise and inward but is not drawn outward. This produces an effect upon the surface as though all the surface molecules were pushing inward equally, and this force, called surface tension, tends to bring any given mass of liquid into the spherical form. — Of course gravitation acting *within* any given mass of liquid or gas tends to bring the mass into the spherical form. As examples, we have the sun and

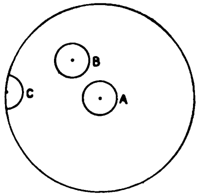

Fig. 11.

the planets. Within small globules of liquids the force of gravitation is so minute as not to be worth mentioning in comparison to "surface tension." In bodies of liquid like planets, however, surface tension would have an immeasurably minute effect, and the spherical form (as the curve of our oceans) would be due to gravitation.

NOTE.—See in larger works and in cyclopædia Prince Rupert's drops, structure (fibrous, granular, amorphous, crystalline), welding, tempering, annealing, shot-tower, and crystallization.

MISCELLANEOUS QUESTIONS.

1. Do we change the weight of a body when we carry it from the base to the summit of a mountain? Do we change its mass?

2. Considering the effect of gravitation alone, a body would weigh more at the equator or at the north pole?

3. How far above the surface of the earth must a 10 lb. weight be carried that it may weigh only 2½ lbs.?

4. A body 12,000 miles above the surface of the earth weighs 64 kgs. What would it weigh at the surface?

5. To what distance does the earth's attraction extend?

6. "Water will not flow by capillarity from the top of a tube." By what experiment would you prove it? [Try the experiment.]

7. Why does dry ground become damp if a coarse sack is left upon it?

8. How is fine shot made?

9. Why do drops of different liquids vary in size?

10. Why do ropes shorten when wet?

11. Why not make pens of cast iron, of lead, of glass, or of tin, instead of making them of steel? Why are pens slit?

12. Could we weigh with *absolute* accuracy and upon a "spring balance," would a body weigh more when the full moon was overhead or six hours later?

13. How would you answer the last if we weighed upon a balance?

14. Suppose we fill a hollow steel cylinder, 5 ft. long by ½ in. inside diameter and closed at one end, entirely full of pure water, and with great exertion (using leverage) we force a tight-fitting steel plunger into it, shortening the column of water by ⅜ of an inch. Would this experiment in the absence of all other testimony prove

that water was compressible? Would it prove that water is not easily compressed? Why or why not?

15. Mention two substances the first harder but less dense than the second.

16. Fill three columns headed respectively volume, mass, and density, with one of these five (1) very great, (2) great, (3) medium, (4) small, and (5) very small, so that the horizontal reading shall be correct. Use each of the five terms once in each column.

17. How would you find out whether a rock possessed a hardness of 6.5?

18. The blacksmith expands the tire by heating, and in resuming its original volume on cooling, it presses the rim firmly upon the spokes. Is this "return" an example of elasticity? Why or why not?

19. What does the physiologist mean when he speaks of the "inelastic" tendons, since you can easily prove that tendons are elastic? He tells you bones are only slightly elastic. The physicist tells you bone is "highly elastic." Explain.

20. Why will not oil and water "mix"?

21. How would you find out how much chalk was used in performing a problem upon the board?

22. How many cu. in. of brass in a solid cylinder 3 in. long by 1 in. in diameter?

23. How many cu. cm. in a lead sphere 6 cm. in diameter?

24. How many cu. cm. of iron in a hollow iron pipe 4 meters long, outside diameter 6 cm., and inside diameter 4 cm?

25. What is meant by a "porous" solid, since all solids have pores?

26. Some writers call the General Properties of matter "Universal Properties." What imperfection of appellation in using "Universal"? In using "General"?

27. Write out five experiments of your own devising which might be substituted for five used in this chapter.

28. Relate an experiment which you have read in some other book.

29. Add something to, or subtract something from, the "comments" in this chapter, which addition or subtraction *you* think would be an improvement.

CHAPTER IV.

FLUIDS.

NOTE. — Liquids and gases because of the many mechanical properties which they have in common, are included under the term fluids. **Hydrostatics** treats of liquids at rest. **Hydraulics** (*hydrodynamics* or *hydrokinetics*) treats of liquids in motion. **Pneumatics** treats of the mechanical properties of gases.

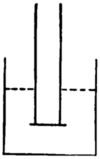

Fig. 12.

EXP. 43. — Place a piece of glass in water; it sinks. Remove and place on ground glass end of open receiver, and holding firmly till glass is a few inches beneath water (Fig. 12), let go of it. It does not sink. ["Rubber dam" obtained from some dentist is useful to prevent leakage between surfaces. Vaseline is excellent for this purpose. If the surfaces are very rough, rubber dam may be used with vaseline. These are almost indispensable in most "air pump" experiments, if cheap apparatus is used.]

(*b.*) Press a beaker (or tumbler) down into water (Fig. 13), and notice that some force resists.

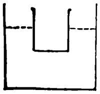

Fig. 13.

(*c.*) Fill a wide mouthed bottle with water. Cover mouth with card and invert suddenly. The water does not run out. Is it a "pushing" or a "pulling" force that holds it in? Remember that "we live at the bottom of an ocean of air."

(*d.*) Place one end of a glass tube (pipette) down into the water, and closing the other end with finger, raise the tube. Remove the finger, the water falls out because of its own weight. [Surface tension takes the place of the card in keeping the water at the lower end approximately level (regular curve), and thus prevents the entrance of air.]

(*e.*) Bend a glass tube at right angles at one end, and lower bent end "squarely" into water, upper end being covered with the finger. Beside it at the same depth place a straight tube of the same length similarly covered, and observe how much the air is compressed in each by the water pressure.

At any point below the surface of fluids at rest, **pressure** is equal in all directions, downward, sidewise, oblique, and *upward*.

Exp. 44. — Bend a glass tube in Bunsen's or alcohol flame, making one long and one short arm. Fill the short arm nearly full of mercury, and lower into a tall receiver of water. Carefully observe the vertical distance between the surface, *A* and *B* (Fig. 14) of the mercury, and compare with the depth (of *B*).

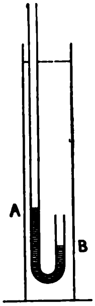

Fig. 14.

Pressure increases **as the depth** of the liquid.

Note. — This statement is not true for great depths, because water is slightly compressible, and becomes more dense as we descend. Could we perform the last experiment at the depths of one mile and of four miles respectively, the pressure would be more than four times as great at the lower depth. The law is, however, practically correct for small depths.

Exp. 45. — Support a large funnel having at least an inch delivery tube, in any convenient way. Close the lower end by rubber dam (Fig. 15, *A*), fastened by waxed thread upon the waxed side of the tube. Fill the funnel slowly with water, and the rubber takes the position *B*. Note carefully this position by measuring from below.

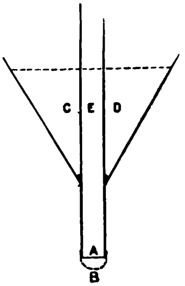

Fig. 15.

(*b*.) Cover one end of a glass tube *E* having the same inside diameter as the delivery tube of funnel, with soft wax, and carefully insert this end so as to shut out the water *CD* on all sides from possibly pressing upon the rubber, and notice if the pressure at *B* is any less.

(*c*.) Remove the tube *E* and insert a tube of about half the diameter (one quarter as large), whose lower end runs through a cork that fits the funnel tube. Does position of rubber *B* change?

(*d.*) Insert in the same way a coiled tube.

(*e.*) Insert an oblique tube, and afterward make the experiment more emphatic by drawing out water *CD* from funnel by siphon.

The pressure on a given area at the bottom of a liquid (or fluid) at rest is equal to the weight of the liquid which would form a geometrical solid vertically above the area to the height of the liquid surface ("*head*").

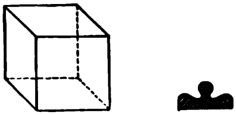
1 CU. CM.
1 GM.

Fig. 16.

One **cubic centimeter** [1] of water weighs **one gram.**

One cubic **decimeter** of water weighs **one kilogram.**

One cubic **meter** of water weighs **one metric ton.**

One cubic **foot** of water weighs about **62.5 pounds.**

Exp. 46. — Make from paper a cubic centimeter and draw on one side a gram weight. Make also a cubic decimeter, and draw upon one side a kilogram weight. These will be very helpful in preventing confusion in working problems. A square-sectioned meter stick with decimeters, centimeters, and millimeters in alternate black and white upon three sides respectively is almost indispensable to clearness in studying the metric system.

QUESTIONS.

1. What weight of water in a rectangular vessel 4 dcm. long by 3 dcm. wide by 2 dcm. deep?
2. What is the pressure on the bottom of this dish?
3. What is the pressure on the side?

[Work as though the side were at the bottom, and take half of this. The pressure on the side *at the top line* is 0. At the bottom line against the side it is the full bottom pressure, and the average pressure is half-way between 0 and the full bottom pressure].

---

[1] At 4° C, except for errors in remote decimal places due to the fact that finite beings can not be infinitely exact.

4. What is the pressure against the gates of a lock, if they are 6 m. wide, and the water above is 5 m. higher than the water below?

5. A dam is 20 m. long, and holds back a pond of water 8 m. deep, the whole width of the dam. What is the pressure against the dam? Does it make any difference whether the pond has an area of *one* acre or of a *thousand* acres? Whether it is deeper or more shoal above?

6. A cavity in the rock on a mountain side has a surface of 20,000 sq. dcm. A crevice from this runs up the mountain a perpendicular distance of 150 m. from the center of the cavity. If cavity and crevice fill with water, what is the pressure on the interior of the cavity tending to burst open the cavity and produce a "land slide"?

7. A reservoir 15 ft. long, 10 ft. wide, and 7 ft. deep, will hold what weight of water?

NOTE. — From Exp. 45 we prove that in three vessels, *A*, *B*, *C*, full of water, of the shape shown by section in Fig. 17, the pressure on the bottom of each is the same, although the weight of the water in each is very different. We should need to make the bottom of dish *C* just as "strong" as the bottom of dishes *A* or *B*, to sustain the weight of the dish full of any liquid.

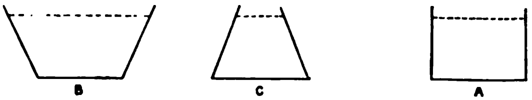

Fig. 17.

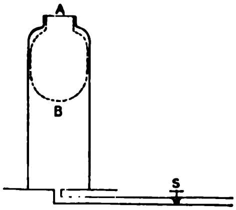

Fig. 18.

EXP. 47. — Place an open receiver, after rubbing the ends with vaseline to prevent leakage, upon the plate of the air pump. Tie over the top a piece of rubber dam *A*, and pump out slowly the air, observing rubber (*B* Fig. 18).

EXP. 48. — Place the palm of the hand over the top of the receiver, and pressing down firmly take a few strokes upon the pump rapidly.

As soon as the pressure becomes disagreeable, open stopcock *S*, allowing outside air to enter receiver. Why could you not remove the hand readily till stopcock *S* was opened? Was the hand "pulled" down or "pushed" down? Why does the under part of the hand covering *A* become red?

Exp. 49. — Place under a closed receiver a rubber balloon *partly* filled with air, and pump out air from receiver. Why does the balloon expand? Open stopcock and admit air.

(*b*) Vaseline a rubber cork and insert in an "empty" bottle. Place under receiver and exhaust air. Why does the cork jump out? Is it pushed out or pulled out?

(*c*) Invert a small bottle full of air, and placing it in a wide mouthed bottle sufficiently filled with water to cover well the mouth of inverted bottle, set the two under receiver and exhaust air. Open stopcock and admit air.

(*d*) Connect two bottles, *A* and *B*, by glass tube, with water in each as shown in Fig. 19. Let *A* be closed by perforated rubber cork, while *B* is open. Place under receiver and exhaust air. Readmit air through stopcock.

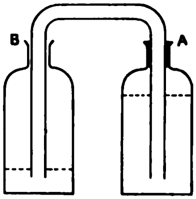

Fig. 19.

"We live at the bottom of an ocean of air." The air about us, though not in the technical sense "compressed air," is really compressed air, compressed by the weight of the air above. When this weight is removed, or partly removed, from any given volume of air, the volume expands according to a well-known law. (See Exp. 63). This is the reason we can pump air (or gases) out from a *closed* receiver. We can not pump liquids out of a closed receiver so long as they remain liquids. Without this tendency of gases to expansion we could not use the air pump at all except as a mere "lifting pump" (Exp. 59). The force per unit area with which a gas tends to expand is called its **tension.**

Exp. 50. — Place a bottle of ordinary drinking-water uncorked under the receiver, and pump out air from receiver. Observe what takes place in the water.

(*b*) **Shake a "water hammer" (glass vessel which has been closed while water was boiling in it) and observe the sharp, metallic sound as the water, entirely freed from air, falls.**

(*c*) **With a clean needle,** *free from rust,* **draw a minute drop of blood from the finger, and placing it carefully upon a glass slide, spreading it out as little as possible, cover with receiver. Pump rapidly while another observes the drop. Why does it expand? The water above did not.**

(*d*) **Place a piece of charcoal in the bottom of a wide-mouthed bottle and load it with a piece of lead. Fill bottle nearly full of water, and placing under the receiver exhaust air.**

(*e*) **Use an "atomizer."**

There is a large amount of air dissolved in water (though the constituents of dissolved air are not in the original proportions). There is a large amount of air dissolved in our blood (chiefly oxygen). The carbon dioxide (a gas) found in the blood is formed principally *in* the body by chemical action. We do not feel the great weight of the air upon us, for the pressure from the outside is met by an equal pressure or tension *from the inside* because of these dissolved gases in the blood. Many solids have the power of condensing within their pores or upon their surfaces, that is, absorbing (or dissolving) large volumes of gases. Especially is this true of many finely divided or "*porous*" solids like platinum sponge, charcoal, etc. The atomizer shows that air adheres to water, but adhesion, friction, and atmospheric pressure are all concerned in its action. Air is not merely pushed into water and blood by pressure.

Exp. 51. — Open the air pump and examine its valves. They may or may not be arranged as in Fig. 20. The valve V in the piston opens at which stroke of the piston, upward or downward? The valve V′ opens at which stroke? Would an air pump work with one valve? Why? The air in receiver *R* expands at each upward stroke of piston just as the air in the rubber balloon of Exp. 49 did. Its return is prevented by the valve V′ at the beginning of the downward stroke of the piston. When the tension of the rarefied air in *R* becomes so little that it will not lift the valve V, the pump can remove no more air.

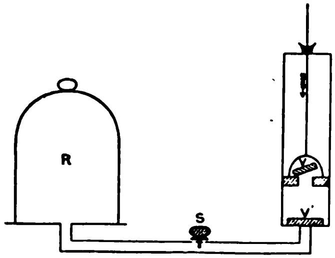

Fig. 20.

Note. — An air pump may be easily made by any worker in brass or iron. The cylinder may be a hollow brass tube of not more than an inch in diameter, and the connections may be made with ⅜ inch gas pipe to small iron or brass plate to hold receiver. Valves should be made of oil silk or of very soft leather, and should be fastened so that they may not fly open too far. The piston should be made up of two brass plates carrying a leathern washer of slightly larger size between them, or the leather washer may be of much larger size and may be rolled down over the lower brass plate. A hole may be bored through the whole and the valve V placed upon the top. Valve V′ may be placed in the upper cylinder head instead of below, when the piston rod must be "packed" where it emerges from the head. — A receiver is easily made by carefully selecting a fruit jar or wide-mouthed bottle and grinding smooth the glass about the mouth on an oiled stone upon which emery powder has been sprinkled. — An open receiver may be made from an Argand lamp chimney by grinding both ends. Rubber dam may be used with vaseline to prevent leakage in case the grinding is not very successfully done.

Exp. 52. — Out of a stout flask furnished with stopcock pump the air. Close stopcock, remove and weigh. Open stopcock while flask is balanced on scales, and weigh again, using milligram weights.

Exp. 53. — Fit a glass tube drawn out fine on the inside of rubber stopple, and out of the same flask pump the air again. Remove from plate, open stopcock under water as shown in Fig. 21. "Fountain in vacuo" appears.

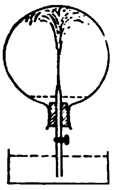

Fig. 21.

Exp. 54. — Pump the air from the "Magdeburg Hemispheres" (Fig. 22.) Close stopcock and remove from the plate. Replace handle and let two pupils try to pull them apart. If hemispheres are small they succeed, if large air must first be admitted.

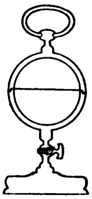

Fig. 22.

Air has weight, and consequently presses down upon the earth just as water presses down upon the bottom of the vessel holding it.

Exp. 55. — Tie a string about a small stone and weigh on delicate spring balance. Lower stone into water and weigh. [Small rubber band and graduated card will answer instead of balance.]

(*b*) Seal carefully with wax the cover upon a baking-powder can. Attach to it a doubled thread. Fasten the handle of the spring balance (a *very delicate* one) to the top of a large receiver, *inside*, with wax or cement. Hang the tin can upon balance and place receiver on plate of air pump. Notice accurately the weight while the "body" hangs in the air. Remove air. Is the *indicated* weight more or less with the air removed? Do we get the true weight of bodies when we weigh them in the water? When we weigh them in the air? Is the *indicated* weight too much or too little when we weigh a body in the air? [To make *delicate* spring balance, see Section I., Appendix.]

That lifting force which makes the indicated weight of a body in a fluid less than the true weight is called **buoyancy.** [See Chapter V.]

Exp. 56.—**"Torricelli's (chĕl'lee) Experiment."** Take a glass tube (closed at one end), about one meter long and three or four millimeters inside diameter. Incline and fill carefully with mercury by means of a funnel with delivery tube drawn out fine. Cover firmly with finger, invert and open beneath a cup of mercury as in Fig. 23. Why does not the mercury run out from the tube? Why does it fall at all? Measure carefully in millimeters the height of the mercury above the level in the dish. In the same dish place similarly a tube of larger size. Allowing for greater *capillary depression* in smaller tube, does the mercury stand at the same height in each? Remove one of the tubes to a dish of mercury of larger area, does the mercury stand any higher or lower than before? If our tube had a sectional area of 1 square centimeter, what would the mercury in it weigh? [Mercury weighs "13.5 + times as much as water."] If the sectional area of our tube were one square inch, what would the mercury in it weigh?

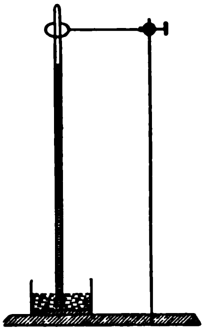

Fig. 23.

The common **Barometer** is simply a "Torricellian tube" filled with mercury, with graduations in millimeters (or inches) that the height above the surface of the mercury in the cup below may be conveniently read. Its office is to indicate the varying atmospheric pressure and *not to prophesy what the weather is to be.* It is a very accurate instrument, doing its work correctly. The predictions which men make from the truth it tells may prove false. A *sudden* and decided fall of the mercury *usually* indicates a storm, while a high barometer usually indicates fair weather. The average height of the barometer at the sea-level is about 760 millimeters, or 30 inches. The atmospheric pressure at this level is therefore about **1 kilogram** per square centimeter, or about **15 pounds** per square inch.

NOTE. — The **aneroid barometer** contains no mercury, but is usually a short metallic circular box from which the air is partly removed. An elastic steel plate receives the varying atmospheric pressure, and connecting with delicate machinery, turns an indicator over a graduated circumference. The graduation is made in millimeters (or inches), by comparison with a standard barometer. A barometer tube might be filled with water, but the tube would need to be nearly 40 feet long as the ordinary height would be about 34 feet. The rise and fall would also be much greater than that of mercury.

EXP. 57. — Place the "Torricellian tube" beneath a tall receiver, and pump out the air. Why does the mercury fall? What would happen if a barometer were carried up a mountain? [A tall receiver is easily made of lamp chimneys (Argand) fastened together by a liberal use of sealing-wax. The top one may be covered with a piece of glass waxed on, and the lower one should be ground to fit plate of pump.]

The barometer is also used in finding the height of mountains. The aneroid being more portable is very useful for this purpose. The barometer falls about 25 millimeters for the first 1,000 feet above the sea level, but not so much for the second thousand feet. At the height of about 3.4 miles the barometer stands one-half its normal height, showing that one-half of the atmosphere is within this distance from the sea-level. Were the whole atmosphere of the same density as at the sea-level, some of the highest mountains would project above it. The height to which the "gradually thinning" atmosphere extends is variously guessed at as from 50 to 250 miles. [See Torricelli, Pascal, Otto Guericke, etc., in cyclopædia.]

EXP. 58. — Bore lengthwise through a piece of wood (*H* Fig. 24), a ¾ inch hole. Stop the two ends with corks. Bore holes through the side, and insert glass tubes of different sizes and funnel as shown in cut. Let *c* be a coiled tube, or one very irregularly bent. Use no tube small enough to be decidedly "capillary." Let *a* be a stout glass tube. Pour water into funnel, and observe the height to which it rises in each tube.

(*b*) Insert piston (rubber cork nailed to end of stick) into *a*, and force it downward. Is there any "*transmission of pressure*" in the tube *H?* Remove piston and tubes *b*, *c*, *d*, and *e*, and stop holes with corks with about the same firmness with which the ends of *H* are fastened. Fill *a* with water, and placing apparatus in sink, force the piston downward suddenly. Several of the corks should fly out. Why more than one? Why not all?

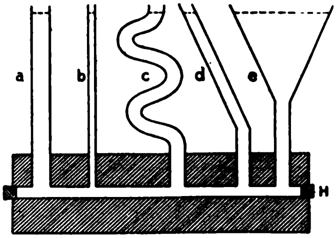

Fig. 24.

(*c*) In place of *a*, *b*, *c*, and *d*, insert capillary tubes of varying sizes by passing them through corks. Pour in water till the funnel stands half full, and observe the height as before.

(*d*) Find out by a good carpenter's "level" which corner of a table is farthest from the earth's center. Also find whether the side of a given cabinet (or post) is vertical.

Under the influence of its own weight alone, in any vessel or connected vessels, **"water seeks its level,"** that is, its surface takes the "earth's curve." If *a* and *d* (Fig. 24) were respectively one mile on opposite sides from *b*, and connected by tube as above, the surface in *b* would stand about 8 inches above the straight line joining the surfaces of *a* and *d*. In the capillary tubes the water is not under the influence of its own weight alone.

Liquids transmit pressure equally in all directions, this pressure acting at right angles to the surfaces pressed. [**Pascal's Law.**] This transmission is practically instantaneous.

Note. — A small column of water (as in *a*, Fig large column in *b*. If the sectional area of th one square centimeter, large column is 100 s then a piston carrying kilogram pressing upo a piston carrying a h pressing on *b*. [See H Chapter XI., and Artesi pædia.]

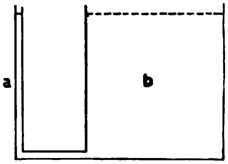

Fig. 25.

Exp. 59. — Take an lamp chimney, large end downward. Cut out a fitting upper portion loosely. Bore through the small hole, and with slender, broad-h fasten to the upper side over the hol valve (V, Fig. 26). Saw off about fo length from a broom handle, cut chisel the center from the end, and on with broad-headed brass nails a twine about the edges of the disl moderately tight-fitting piston. Inse portion of chimney a perforated woo the top of which is fastened a Make plug tight with wax. With s wet with turpentine (camphor may be dissolved in it to advantage) bore a small hole through side o chimney near the top, and attach with wax a hollow glass tube for a spout. Cut away the handle above to give room for the water to rise. Pump with the apparatus, watching action of the valves.

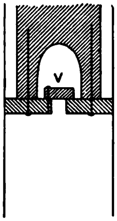

Fig. 26.

The **Lifting Pump** was formerly calle pump. The atmospheric pressure, transfer the water, pushes the water up to the valve is pumped out of the tube leading from the fore these valves must be within 34 feet o surface below. Practically the valves mu 28 feet or less. The atmospheric pressu

elp (i.e., furnish energy) in the pumping, for
ses equally up from below and down from
the piston.

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with rod. At the bottom [illegible]
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At the upward stroke of the piston [illegible]
downward stroke? What is the [illegible]

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Hydraulic Ram. Chapter [illegible]

In a gas stopcock [illegible]
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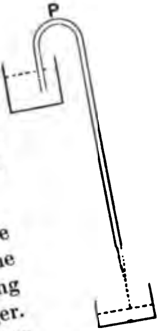

Fig. 35.

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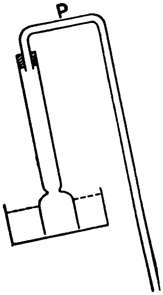

Fig. 36.

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NOTE.—A small column of water (as in *a*, Fig. 25) will balance a large column in *b*. If the sectional area of the small column is one square centimeter, and that of the large column is 100 square centimeters, then a piston carrying a weight of one kilogram pressing upon *a* will balance a piston carrying a hundred kilograms pressing on *b*. [See **Hydrostatic Press,** Chapter XI., and **Artesian Wells** in cyclopædia.]

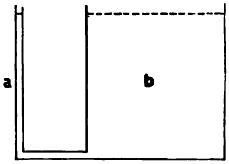

Fig. 25.

EXP. 59.—Take an ordinary student-lamp chimney, large end downward. Cut out a thin disk of wood fitting upper portion loosely. Bore through the center of wood a small hole, and with slender, broad-headed brass tacks fasten to the upper side over the hole a soft leathern valve (V, Fig. 26). Saw off about four decimeters in length from a broom handle, cut out with narrow chisel the center from the end, and fasten the disk on with broad-headed brass nails as shown. Wind twine about the edges of the disk to complete a moderately tight-fitting piston. Insert in the narrow portion of chimney a perforated wooden plug, upon the top of which is fastened a valve (Fig. 27). Make plug tight with wax. With small rat-tail file wet with turpentine (camphor may be dissolved in it to advantage) bore a small hole through side of chimney near the top, and attach with wax a hollow glass tube for a spout. Cut away the handle above to give room for the water to rise. Pump with the apparatus, watching action of the valves.

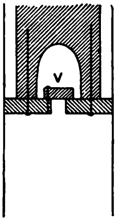

Fig. 26.

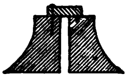

Fig. 27.

The **Lifting Pump** was formerly called a suction pump. The atmospheric pressure, transferred through the water, pushes the water up to the valves as the air is pumped out of the tube leading from the well, therefore these valves must be within 34 feet of the water surface below. Practically the valves must be within 28 feet or less. The atmospheric pressure, however, does not help (i.e., furnish energy) in the pumping, for the air presses equally up from below and down from above upon the piston.

Exp. 60. — **Take an Argand lamp chimney and fit to it a solid (valveless) piston with rod. At the bottom place a doubly perforated wooden stopple that has been over night in water, and to which a valve V and glass tube *S* has been attached as in Fig. 28. Through the other orifice, pass a bent glass tube into a reversed bottle, *C*, with valve V′ in stopple as shown and delivery tube *d*. Place tube *S* in water beneath some suitable wooden support for apparatus and pump, observing the valves V and V′ and the water in *C*. Rubber tube may be placed over *d* to prevent water from escaping the sink. Notice that a valve is *not an opening*, but a door covering an opening, and that it opens in the direction in which the fluid is moving. At the upward stroke of the piston what do the valves do? At the downward stroke? What is the air chamber for?**

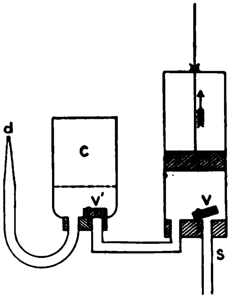

Fig. 28.

The **Force Pump** is used for raising water to great heights. It is frequently worked by a steam engine or dynamo. The **air chamber** *C* prevents shock to the machinery and gives a continuous stream. Fire engines have double cylinders connecting with air chamber, so that there is a nearly continuous downward stroke of one piston. [See Hydraulic Ram, Chapter XI.]

Exp. 61. — **Fasten a gas stopcock into a perforated rubber cork, and insert this in a gallon demijohn. Connect stopcock and tube *d*, Fig. 28, by rubber tube. Pump rapidly *the air*, and have another close quickly the stopcock after eight or ten complete strokes have been taken. Remove rubber tube from *d*, and connecting with Barker's Mill (reaction wheel) at *f*, Fig. 30, open stopcock.**

NOTE. — A Barker's Mill is easily made by taking four short pieces of glass tubing drawn out and bent at one end, and arranged as in Fig. 29 upon soft wax. The inner circle *E* represents a disk of metal to support wheel upon pivot, and the dotted circle the disk of wax upon which the tubes *a*, *b*, *c*, and *d* are laid with ends upon disk *E*. At right angles to the four tubes place a larger tube (not shown in figure, say *x*), about six centimeters long, its lower circumference resting upon the four tubes above the metallic disk. Wax the whole together so that when you blow into the tube *x* the air will come out freely at the ends of *a*, *b*, *c*, and *d*. Run a darning-needle, *n*, Fig. 30, *at right angles* through a large flat cork. At the bottom wax the horizontal tube *f* connecting with a vertical tube *e*. The tube *e* should be just large enough to admit freely the tube *x*, and the needle should project a little above to receive the disk *E*, Fig. 29, upon its point. Blowing gently at *f* sets the wheel in motion.

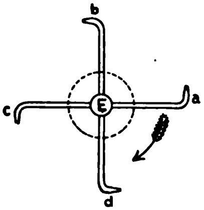

Fig. 29.

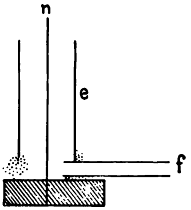

Fig. 30

(*b*) Condense air in demijohn again, and waiting till temperature of demijohn is normal, again place bulb of thermometer at the orifice, and open stopcock. Does the mercury rise or fall?

Machinery may be run by compressed air. A force pump for condensing air is called a **condenser**. Of course there is no need of any "air chamber" (*C*, Fig. 28). The moisture in the air, however, is a difficulty to be overcome, as condensation and a cooler temperature tend to change the vapor of water to a liquid, clogging the pipes and cylinder in which the piston moves. The compressed air as it expands absorbs heat producing great cold, which tends to freeze the vapor of water. This becomes an insurmountable difficulty when air at igh pressure (above about 60 pounds per square inch) s released. [See Heat.]

Exp. 62. — Fasten copper wire to the *perforated* cork which closes a long narrow test-tube, till the tube will almost but not quite sink in water. Place the tube in a *narrow*, deep receiver filled with water, and tie over the end of receiver (*a*, Fig. 31) rubber dam. Press with the *palm of the hand* (not with fingers) upon dam, and then release pressure. As the tube rises and falls, observe what happens *within* the tube, that you may tell why it rises and falls. "Bottle imps" are usually provided with hollow *coiled* tails so that they may turn (dance) on the principle of Barker's Mill. [See Exp. 90.]

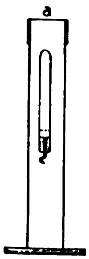

Fig. 31.

Most fishes are **"bottle imps"** or "Cartesian divers." They can fall or rise without moving fins by compressing or relieving pressure on "air bladders."

Exp. 63. — Bend a stout glass tube as in Fig. 32 and clamp by soft wooden buttons to support. The long arm should be a meter long, and the short arm 20 centimeters (of straight tubing above bend). Graduate each tube in centimeters, the short arm from the top downward. Cut a notch into support above *A* and grind the end smooth with small flat file. Fasten just above *A* an old "binding-post." Place a piece of leather and rubber dam between the screw head and *A*. Pour into the long arm a little mercury and bringing its level, by inclining tube if necessary, just to the 20 centimeter mark in short tube, screw backward and down upon the end *A*, the screw-head making the tube air tight. There is now in the short arm a pressure of one atmosphere on the volume of air, just the same as before its confinement in the tube. Notice how high in millimeters the barometer stands, and gradually pour *one-fourth* as many millimeters of mercury into the longer arm, measuring as the height the *vertical difference between the two levels*. Notice how much the column of air *AB* has shortened. Pour on till you have half as much mercury as the barometer shows, and observe columns

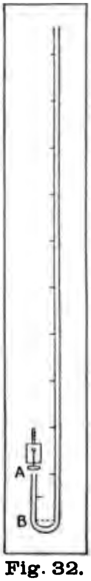

Fig. 32.

Afterwards pour on three-fourths and then just as many millimeters as the barometer indicates. How many atmospheres pressure have you now upon the gas? How much volume has it? Is its tension (elasticity) greater or less than before? Is there any more or less matter other than mercury in the short tube?

Mariotte's Law. *Temperature remaining the same, the volume of a gas is inversely as the pressure upon it and the density and tension are as the pressure.*

This law is sometimes called **Boyle's Law.** [This law is approximately correct, but does not hold true at all at *very high* pressure.]

EXP. 64. — Fit a piston tightly into an Argand chimney. Over the ground top place a large perforated rubber cork from which passes a glass tube connecting with a stout rubber tube at *a*, Fig. 33. Vaseline well that there may be no leakage. Support chimney in a wooden frame and hanging a weight *W* upon piston *P*, connect tube *a* by open stopcock to plate of air pump. Exhaust air. What lifts the weight? The apparatus is called a "weight-lifter." [A large one sufficient to lift a pupil easily, makes a very impressive lecture-room experiment.]

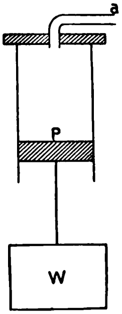

Fig. 33.

(*b*) Cut out a cavity from the large end of a soft rubber cork. Vaseline edge and press firmly down upon a piece of heavy glass. What force (*principally*) lifts the glass when you raise the cork? What then do *you* "lift"?

A "sucker" may be made of leather with attached string and acts upon the same principle as the cork in *b*. Adhesion and cohesion may hold light substances as paper to the sucker, but the principal force which holds heavier substances is unbalanced atmospheric pressure. When the sucker is raised *part* of the pressure of the air is taken off *part* of the top of the object lifted, while the full upward pressure remains at the bottom. Insects often crawl on smooth surfaces, and marine animals "cling" to rocks on the same principle.

Exp. 65. — Place a small brass chain with one arm hanging down longer than the other over a bottle *B* held horizontally as shown in Fig. 34. Let go the chain. Why does it "flow"? The unbalanced weight upon the two arms is like unbalanced forces anywhere. "Unbalanced forces produce motion." Why does not the brass chain break at the highest point *P?* Could the chain be made long enough to break from its own weight, both arms falling?

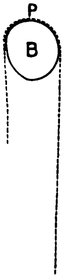

Fig. 34.

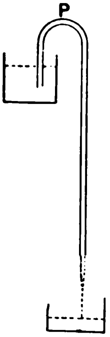

Fig. 35.

(*b*) Bend a small glass tube into the shape of this chain, and fill with water. Place the finger over the end of long arm, and placing the end of short arm in water remove finger. Why does the water "flow"? What holds the water chain together and prevents its breaking at *P?* [Not cohesion. This force is not strong enough to hold *an ordinary* "water-chain" together, that is, water containing dissolved air. Adhesion and cohesion together hold a "chain" of water only about one centimeter long against the force of its own weight, as you may see by lifting the upper end of glass tube out of water.]

The **Siphon** is a bent tube by which liquids may be transferred from one vessel over into another, the unbalanced weight in the two arms causing the flow, and the atmospheric pressure keeping the bent water column from parting. Of course gases "heavier than air" may also be siphoned, and those "lighter than air" may be *reversely* siphoned.

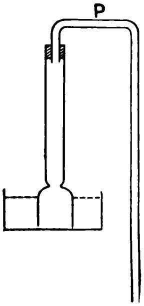

Fig. 36.

Exp. 66. — Arrange a lamp chimney, perforated cork, and bent glass tube for a siphon, successively, as shown in Figs. 36, 37, and 38. Will the apparatus work as a siphon in all the cases? Why or why not? The weight of the water in the short arm of Fig. 36 is greater than the weight in the long arm. If "unbalanced weight" makes the siphon flow, why does it not flow the other way?

Just as the expansion or contraction of a dish from the bottom upward does not increase nor diminish the pressure on the bottom, so the expansion or contraction of any portion of a siphon does not increase nor decrease the "weights" tending to "balance" in each arm. The "balancing weight" for the short arm is the weight of water which would form a vertical column, having a uniform sectional area equal to that of the smallest portion of the siphon, from the surface of the source of supply to the highest point of the siphon. The "balancing weight" for the long arm is the weight of a similar column from the highest point of the siphon to the discharging orifice (or to the surface of the receiving vessel if the siphon discharges beneath this surface as in Fig. 38). These "balancing weights" are of course as these distances, so that the greater the difference between these distances the more unbalanced the weights become, and, other things being equal, the more rapidly the liquid flows in the siphon.

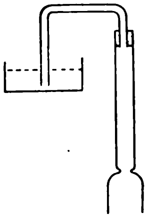

Fig. 37.

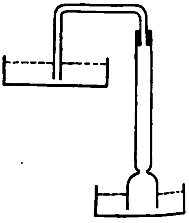

Fig. 38.

Exp. 66, (*b*).—Arrange apparatus as shown in Fig. 39. *A* is a tin pail with a small tube *a* emptying water into a glass dish *B*. This has a siphon tube larger than *a* waxed into a hole drilled through the dish. The highest point *P* is lower than the surface of the water in *B* when *B* is full of water. Keep *A* full of water by pouring from pitcher, and watch the discharge at the orifice.

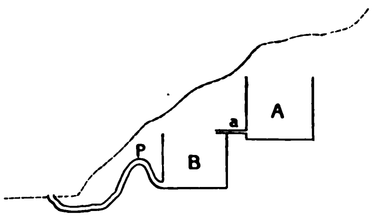

Fig. 39.

Intermittent Springs are usually formed by a siphon-shaped delivery tube (or crevice) proceeding from a cavity. This cavity is fed by underground rivulets more slowly than the siphon, *while at work*, discharges the water.

MISCELLANEOUS QUESTIONS.

1. Mention five instances (with open books) in which the comments following experiments in this chapter teach more than the experiment teaches.

2. Mention five instances in which the experiment teaches something not mentioned in the comments.

3. Did we prove that "Pressure increases as the depth" in all liquids?

4. How many grams of water will a vessel hold that is 15 cm. long, 5 cm. wide, and 4 cm. deep?

5. How many kilograms of water in a full tank 5 m. long, 4 m. wide, and 8 dcm. deep?

6. How many metric tons of water in a full reservoir 80 m. and 5 dcm. long, 50 m. and 4 dcm. wide, and 8 m. and 5 dcm. deep?

7. What will the water weigh in a full tank 8 ft. 4 in. long, 6 ft. 8 in. wide, and 5 ft. 2 in. deep?

8. By which system of weights and measures would you prefer to work one thousand of such questions, the metric or the English system? Why?

9. Draw a section of a lifting pump, showing valves plainly at upward stroke of piston.

10. Draw a section of a force pump, showing valves and air chamber at the downward stroke of piston.

11. Let the area of the piston in Fig. 40 be 4 sq. cm., and the depth of the cylinder 20 cm. The atmospheric pressure being 1 kg. per sq. cm., with how many kilograms pressure must a man push upon the piston rod *A* to force the piston *P* into the cylinder 15 cm. deep to *P′*, provided air in cylinder is kept at the same temperature?

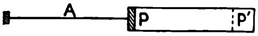

Fig. 40.

12. Let *C D* (Fig. 41) be a horizontal line, *A* and *C* two valleys on opposite sides of the hill *B*. Let vertical *B F* be 45 ft., *A E* be 7 ft., and *S D* be 30 ft. Can the water be siphoned from a tank at *A* to *C*? (*b*) Can it be siphoned from *S* to *C*? Why or why not?

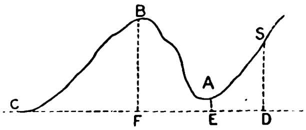

Fig. 41.

13. If we have 24 cu. dcm. (liters) of air in a cylinder, and we

put two more atmospheres pressure upon it, how much will be the volume of the gas?

14. If the air in the chamber of a fire-engine be condensed to 1-10 of its former volume, what is the pressure (*tension*) per sq. cm. inside the chamber?

15. Give an illustration of the use of the mouth as an air pump. (*b*) As a condenser.

16. Why is it very tiresome to walk in wet clay?

17. In Exp. 49 (*b*) why is the word "empty" put in quotation marks? What is often the meaning of these marks in scientific books?

18. Why do bubbles of air become larger as they ascend in water?

19. In laying railroad tracks, does the surveyor allow for the curvature of the earth? (*b*) If the rails run in mathematically straight lines horizontally a distance of 20 miles, 10 miles on each side of a town, the incoming or the outgoing train can make greater speed. Why?

20. Mercury is about "13.5 times as heavy as water," how high a point above surface of supply may it be carried *over* in a siphon?

21. Invent five experiments that might have been properly inserted to prove or illustrate principles set forth in this chapter.

22. Mention a good experiment which you have read about in some other book.

23. Mention some experiment which *you* have performed not laid down in the books.

24. Give illustrations from real life, outside of school, of your own observing.

CHAPTER V.

DENSITY AND SPECIFIC GRAVITY.

ONE **cubic centimeter** of water weighs one **gram.**

EXP. 67.—Procure a glass marble and a lead bullet of the same size, carefully measuring with calipers. Weigh each. If the lead weighs 45.4 grams and the glass 11.35 grams, the lead weighs four times as much as the glass, and we have

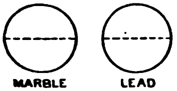

Fig. 42.

wt. of a given volume of lead : wt. of same vol. of glass :: 4 : 1.

We express the same fact when we say that lead is 4 times as dense as glass, or that the specific gravity of lead is 4, *compared with glass.*

Density is the *amount of matter* (mass) in a unit volume. **Specific gravity** is the *ratio* between the weight of a given body and the weight of an equal volume of some substance taken as a standard. Water (at its greatest density 4° C.)[1] is taken as the standard for solids and liquids, and air (0°, barometer, 760 mm.) for gases. When we say that the specific gravity of a solid is 2, we simply abbreviate a ratio, 1 for water being understood. The same abstract *number* may express both the density and the specific gravity. Density is usually estimated in *grams per cubic centimeter.* Specific Gravity is the ratio between the density of a body and the density of the standard. [Water at about 15° C. or 60° F., is taken as the standard in some tables of specific gravities.]

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[1] See foot-note, page 31.

Exp. 68. — Place the top of a cubic decimeter of wood o meter deep in water, and from your kn of "pressure and depth" compute t sure on top (downward), and the pres the bottom (upward). Place it at t meters deep, and compute pressure on at the bottom as before. Is the *buoya* more or any less at the latter depth ? Exp. 55 (*a*) with the stone at various Is the buoyancy *constant* at different d

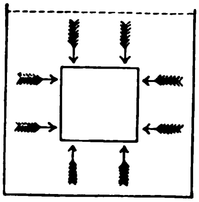

Fig. 43.

Exp. 69. — "**Cylinder and Buck** periment. Let *a* be a solid brass cylinder just fitting the (Fig. 44). Weigh carefully and bucket upon specific scales (scales having a ho one scalepan, and a sto wire soldered to upright extended on each side *c*, *d*, port beam that it may not t veniently far from the hor Raise scale while balan lower solid cylinder into w *large* surface *level with top* cylinder before scales are Why is the balance de Restore the balance by putting water into the bucket *b*. In

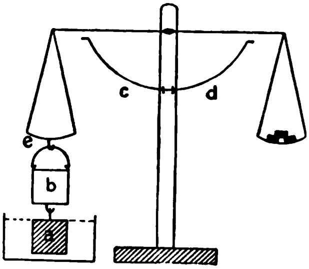

Fig. 44.

Archimedes' Principle. *A body immersed in is buoyed up with a force equal to the weight of th displaced.*

Note. — This buoyancy is conveniently called "loss of and the balance left after subtracting the buoyancy of the conveniently called the "weight in water." The remain subtracting the buoyancy of the air is called the "weight The weight in air of solids and liquids, unless otherwise me will be assumed as the true weight. [See weight, p Ordinary drinking-water at the temperature of the schoolro be used for distilled water at 0° with approximately correct

EXP. 70. — To find the specific gravity of an ordinary solid.

1.	Wt. in air	50 gms.
2.	Wt. in water	35 gms.
3.	Loss in water Wt. equal vol. water	15 gms.

50 ÷ 15 = 3.3 + sp. gr. *Ans.*

Perform this experiment using an ordinary stone. Find the specific gravity of pieces of lead, brass, etc., comparing results with the Table of Specific Gravities (Appendix, Section III.). Tie round each substance a slender thread with loop to fasten to hook of scalepan. A balance beam that slides upon the upright rod of scales is convenient, but the same result may be reached with wooden blocks adjusted under either the scales or the vessel holding water. Do not expect to get the *precise* results given by the books. Two different pieces of brass or of glass may have different specific gravities.

EXP. 71. — To find the specific gravity of a **liquid.**

(*a*)

1.	Loss of stone in water Wt. of equal volume of water	20 gms.
2.	Loss of same stone in liquid Wt. of equal volume of the liquid	16 gms.

16 ÷ 20 = .8 sp. gr. *Ans.*

(*b*)

1.	Wt. of bottle	25.6
2.	Wt. of bottle full of water	125.6
3.	Wt. of bottle full of liquid	135.6
4.	Wt. of water (125.6 — 25.6)	100.
5.	Wt. of equal vol. of liquid (135.6 — 25.6)	110.

110 ÷ 100 = 1.1 sp. gr. of liquid. *Ans.*

NOTE. — A bottle which holds just 100 gms. of water (sometimes 0 gms., 50 gms., etc.) is called a *specific gravity bottle.* A counterpoise weight (equal to the empty bottle) is very convenient.

(c)

Place a graduated float, called an **hydrometer**, into
deep receiver filled with distilled water or rain wa
observe how deep it sinks. Fill the receiver wi
urated solution of common salt (water containin
salt it will dissolve), and insert hydrometer. Th
tion will show the specific gravity of the salt wa
the hydrometer sink deeper or not so deep in salt

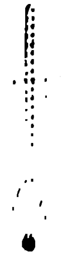

Fig 45

NOTE. — An hydrometer can be made by gra
wooden rod about 40 centimeters long of *uni
section*, loading the bottom with lead, and par
well *(not thickly)*. The specific gravity of an
inversely as the depth to which *this* hydrome
Hydrometers take various names according to
of the liquid whose specific gravity they are to i
alcoholometers, lactometers, etc.

(*d*)

Bore three holes through a large rubber stopple that fit
wide-mouthed bottle. Into the middle
a glass tube bent at right angles on o
having a thin walled rubber tube atta
Fig. 46. Insert straight glass tubes abo
meters long as shown at *b* and *c*, p
down into water, and the other into
whose specific gravity is to be found.
effect of capillarity. Exhaust the air b
mouth at rubber tube connected with *a*,
the liquids stands about 4 decimeters
close rubber tube by pressure. Measur
the height of each liquid above heig
capillarity. The specific gravities are i
the heights, as:

1. Water stands at height of . . . .
2. Liquid stands at height of . . . .

45 ÷ 30 = 1.5 sp. gr. of liqui

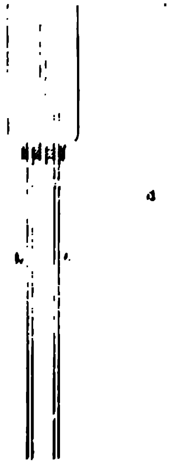

Fig. 46.

EXP. 72. — To find the specifi
of a **soluble** solid [i.e. one sc
water as rock salt].

Take some liquid in which the solid will not dissolve. Find the specific gravity of this liquid and proceed as follows:—

1.	Wt. in air		60
2.	Wt. in liquid (whose sp. gr. is 1.1)		38
3.	Loss in liquid		22
4.	Loss in water Wt. equal vol. water	[22 ÷ 1.1]	20.

$60 \div 20 = 3$ sp. gr. *Ans.*

NOTE.—There is almost always one liquid readily obtained, which will not dissolve any given soluble solid, and that is a saturated solution of that solid.

EXP. 73.—To find the specific gravity of an insoluble solid, **"lighter than water"** [e.g., cork].

1.	Wt. in air		5.2
2.	Wt. of lead sinker *in water*		40.
3.	Wt. of substance and sinker *in water*		20.2
4.	Loss in water Wt. equal vol. water.	[5.2 + 19.8]	25.

$5.2 \div 25 = .2 +$ sp. gr. *Ans.*

NOTE.—Tie the sinker with double loop, long and short. Attach long loop to hook on scalepan to weigh sinker in water, and to weigh substance and sinker in water pass long loop attached to substance through short loop attached to sinker. The loss of weight of the substance in water is composed of two elements, (1) the whole of its own weight, and (2) all it "takes off" from the weight of the sinker. The "weight in water" of such a substance is of course negative. In the example above the "weight in water" is -19.8. A very "porous" body like cork has its cavities filled with air. This gradually gives place to water as the body remains submerged, and of course the buoyancy grows gradually less. A water-soaked log is much heavier than a dry log, because the minute gaseous cavities have all been filled with water.

Exp. 74. — To find the **volume** of an irregular solid [i.e., one whose average length, breadth, and thickness can not be readily determined by direct measurement].

1.	Wt. of rough stone in air	60.4 gms.
2.	Wt. of rough stone in water	40.8 gms.
3.	Loss in water or Wt. equal vol. of water	19.6 gms.

One gram of water has a volume of **1 cu. cm.**
19.6 gms. have a volume of 19.6 cu. cm.

The stone has the same volume as the displaced water, therefore, —
volume of stone = 19.6 cu. cm. *Ans.*

Note. — Of course this same method may be used to find the volume of any solid, however regular.

Exp. 75. — To find the specific gravity of a *finely divided* solid, as sand.

Make a Nicholson's hydrometer (Fig. 47, *a*), as follows: —

Solder two brass wires 6 centimeters long to the bottom of a small baking-powder can, and one wire about 10 centimeters long to the center of the top. The can should previously be made air tight. Fasten a round sheet of lead *b* ("lower pan") to the two wires, and a flat cork *c* ("upper pan") to the top wire. Set the hydrometer into a deep receiver of water, after placing a mark on the center of the upper wire below the cork to which point the *weighted* hydrometer is to sink. Place a piece of glazed paper on upper pan to hold sand, and upon this place weights to sink hydrometer to mark. Wire support should be placed across the top of the receiver to prevent the accidental sinking of the upper pan, and the paper to hold sand should remain all the time on the upper pan, and all weights should be placed there.

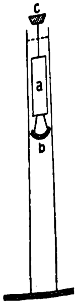

Fig. 47

1.	Wt. necessary to sink hydrometer to mark .	24. gms.
2.	Wt. necessary to sink with sand on upper pan,	16. gms.

24 — 16 = 8 gms., wt. of sand in air.

3. Wt. necessary with sand on lower pan . . . 19.2 gms.

19.2 gms. − 16 gms. = 3.2 gms.

4. $\left\{\begin{array}{l}\text{Loss of wt. in water}\\ \text{Wt. equal vol. water}\end{array}\right\}$ . . . . 3.2 gms.

8 ÷ 3.2 = 2.5 sp. gr. of sand. *Ans.*

Note. — The specific gravity of any insoluble solid "heavier" or "lighter" than water may be obtained by using Nicholson's hydrometer, but this method is not quite so accurate as the method with the balance. A metallic bucket may be used to find the specific gravity of sand by means of several weighings.

Exp. 76. — To find the **mass** of a body having its volume (dimensions) and specific gravity given.

A brick of silver (sp. gr. 10.5), 10 cm. long, 6 cm. wide, and 4 cm. thick, weighs how much?

1. 10 × 6 × 4 = 240 cu. cm. = volume (bulk or contents).
2. It would weigh 240 gms. *if water*,

but being 10.5 times as heavy as water, it weighs

3. 240 gms. × 10.5 = 2520 gms. *Ans.*

Exp. 77. — Fill with water dish *a*, Fig. 48, from which a fine glass tube *b* emerges as shown. Observe the height of the water in tube *b* after it has been wet above surface of liquid by rubbing with fine wire. (Why?) Mark by putting wet red litmus paper on side of tube. — Weigh a heavy bottle that will just float in water with stopple in. Place this bottle in dish *a*. What effect upon water in *b*? By means of a pipette previously wet remove water from *a* equal to the weight of the floating bottle, and observe height of surface in *b*.

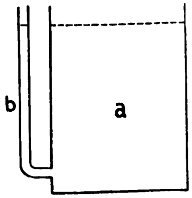

Fig. 48.

A **floating body** influenced [illegible] weight and [illegible] [illegible] its own weight of the liquid in which [illegible]

[illegible] Take an iron screw whose specific gravity [illegible] [illegible] about 7.5 and throw it [illegible] [illegible] specific gravity [illegible].

[illegible] dry fine needle (specific gravity 7.8 — [illegible] [illegible] small a height as possible upon water. [illegible] [illegible]

[illegible] the influence of weight and buoyancy only, a body sinks [illegible] liquid whose specific gravity is less than its own, and floats [illegible] liquid whose specific gravity is greater than its own. [illegible] [illegible] as "a body" which includes space enclosed [illegible] gravity is less than that of water. All ordinary floating [illegible] are considered to be under the influence of weight and [illegible] [illegible] floating bodies which are not wet by the li[illegible] [illegible], affected by a *third force*, surface tension. Exp[illegible] [illegible] needle displaces several times its volume of wat[illegible] [illegible] 7.8 times its own volume, in other words [illegible] The surface layer of the liquid resists the pa[illegible] [illegible], *apart from any effect due to* buoyancy. It shou[illegible] [illegible] that buoyancy is a force due to weight, its up[illegible] [illegible] the transferred downward "pushing" [illegible] [illegible] the liquid.

[illegible] Blow soap bubbles with illuminating gas (or [illegible]) and detach from pipe. Why do they ascend? Ar[illegible] [illegible] pushed up or pulled up?

Try blowing bubbles with carbon dioxide. (Borrow generator [illegible] the chemical laboratory.) Do they ascend? Why or why not

Balloons ascend because of the buoyancy of the air. They [illegible] ascending when they reach a stratum of air of the same s[illegible] gravity as the balloon, including contents. [See balloon, para[illegible] etc., in cyclopaedia.]

EXP. 80. — To find the **density of air;** that is, to find the weight of 1 cu. cm. of air. This will be numerically its specific gravity with reference to water.

Solder a stopcock to a stout can (*C*, Fig. 49) whose inside volume has been carefully measured. Attach this can to the plate of the air-pump. Attach as shown a mercurial gauge *G*, a bent glass tube whose closed arm is filled with mercury. On its supporting stand is a millimeter scale. Exhaust the air very slowly till the difference in level of the mercurial surfaces is, say, three-tenths the height of the barometric column. The two surfaces would be at the same level if all the air were exhausted. Seven-tenths of the air have been removed. Close stopcock, remove can, and weigh carefully. Admit the air, wait a few minutes, and weigh again. Compute density as follows:

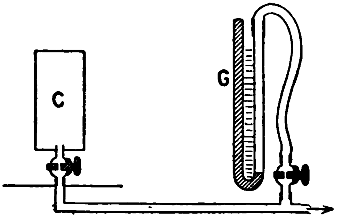

Fig. 49.

1. Volume of can (say)	1100 cu. cm.
2. Difference in weight	993 mgs. (.993 gms.)
3. Difference if all air were exhausted . .	1.419 gms.
4. Weight of 1100 cu. cm. of air	1.419 gms.

One cu. cm. of air weighs [1.419 gms. ÷ 1100] .00129 gms. (1.29 mgs.)

Density of air = .00129 gms. per cu. cm. *Ans.*

NOTE. — This fraction is about $\frac{1}{770}$. The specific gravity of air, therefore, is about $\frac{1}{770}$, with water as the standard; that is, water is about 770 times as heavy, volume for volume, as air. [*For allowances made for temperature and barometric pressure*, see HEAT.]

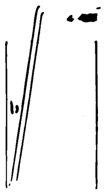

Fig. 60.

Exp. 81. — To find the specific gravity of a gas with air as the standard. Balance with weights upon delicate scales an air-tight can with a piece of soft wax on top of it. Remove can, and making with coarse awl a hole in the top, enlarge and insert glass tube (C, Fig. 59) and borrowing from chemical laboratory, pass carbon dioxide [through wash-bottle of cold water and through drying-bottle of calcium chloride, if more accurate results are desired] into the can. When filled, remove tube while gas is passing, and quickly stop hole with wax. Weigh again and note carefully the increase of weight in milligrams. Compute specific gravity of the gas as follows: —

1 Volume of can inside (by measurement) . . . . 600 cu. cm.
2 Wt. of air in can [1.29 mgs. × 600] . . . . . . 774 mgs.
3 Increase of weight . . . . 405 mgs.
4 Wt. of carbon dioxide in can [774 + 405] . . . . 1179 mgs.

1179 : 774 1.52 + specific gravity of carbon dioxide. *Ans.*

Note. To find the specific gravity of a gas "lighter than air," as coal gas, simply reverse the can while filling. [See ventilation.]

MISCELLANEOUS QUESTIONS.

1. What is the difference between density and specific gravity?

2. Why is a liquid rather than a solid chosen as the standard for specific gravity for both liquids and solids? Among liquids why is water chosen? Why is air taken as the standard for gases?

3. Just what did we prove by Exp. 69, *instead* of Archimedes' Principle? "That a solid brass cylinder immersed in water," etc. *Ans.*

4. A body whose sp. gr. is 4, loses what part of its weight in water? (*b*) Wt. in air 60, sp. gr. 4. Wt. in water?

5. Wt. in air . . . 40, in water . . . 25. Sp. gr.?

6. Wt. in air . . . 80, in sulphuric acid (sp. gr. 1.8) . . . 44. Sp. gr.?

7. Wt. of stone in air . . . 70 gms., in water . . . 60 gms. Volume of stone?

3. Wt. of stone in air . . . 70 gms., in water . . . 60 gms., in ted sulphuric acid . . . 55 gms. Sp. gr. of the acid?

9. How would you find the sp. gr. of a soluble solid?

.0. Wt. in air . . . 10, wt. of sinker in water . . . 40, wt. of sub- nce and sinker in water . . . 25. Sp. gr. of substance?

11. A nugget of gold loses 15 gms. in water. Volume?

12. A piece of steel loses 125 lbs. in water. How long is it if its iform sectional area is 36 sq. in.?

13. If 30 gms. sink hydrometer, if sand plus 20 gms. sinks it, and sand on lower pan plus 25 gms. sinks the instrument, what is the gr. of the sand? [Fig. 47.]

14. A flatboat 20 m. long, 8 m. wide, sinks 6 dcm. deeper when led with potatoes. How many metric tons of potatoes in the l?

5. Given a pair of scales weighing only 250 lbs., and other lities as you might wish, how would you weigh a live elephant?

). A piece of lead, sp. gr. 11.3, is 8 dcm. long, 6 dcm. wide, and m. thick. What does it weigh?

. Why do the bodies of persons drowned usually come to the ce after several days? Why will firing heavy guns frequently ; such bodies to the surface earlier than they would otherwise Why do not bodies in *very deep* lakes come to the surface ı? Do drowning people "*rise three times*" before finally ng?

A balloon is intended to rise 3.4 miles. [*See comments*, *Exp.* ld Mariotte's Law.] Why should it not be *completely* filled coal gas before starting?

What would happen if we should sink an *ordinary bottle* of arefully corked, *deep* into the *ocean*? If we should pump the om a *very thin* bottle?

Why is the *density* of any *substance* in *grams per cubic centi-* numerically equal to the *specific gravity*, with *water* as the ard? [But see *foot-note*, *page* 3[illegible].]

A soap-bubble *slowly rises* in the air: do we know that the ı it is "lighter than air"? A *soap-bubble slowly sinks* in the o we know that the gas in it is "*heavier than air*"?

22. Why will oil float on water? A pail partly full of water weighs 16 lbs. A fish weighing 4 oz. is dropped into the pail and floats at its center. What does the pail of water weigh with the fish in it?

23. The water which you have used as a standard probably contains carbonates, sulphates, or other solid matter dissolved in it; how does this fact affect your results? Because of this are the specific gravities which you have obtained too large or too small?

24. The water which you have used has been *too warm*, how has this fact affected your results?

25. A "porous" brick weighs 2.5 kgs. in air, and 1 kg. in water. After soaking over night it weighs 1.5 kg. in water, and 3 kgs. in air. Sp. gr. (1) of *dry* brick? (2) Of *wet* brick? and (3) of the *material* of which the brick is made?

CHAPTER VI.

MOTION, FORCE, ENERGY.

. —Place a coin upon a card, and put the card over the
ı of a bottle (Fig. 51). With an elastic strip
r metal, snap the card vigorously, driving it
y. What *tendency* does the coin show in addi-
tendency which gravitation gives it, that is,
ncy "of itself" does it show?
a ball upon a smooth, level board till it
endicularly some heavy obstruction. Did the
itself?" Does it show any perceptible in-
crease of velocity before reaching the obstruc-
e a sliver oblique to ball's path, and roll again.
it not roll in a straight line now? Prop up
the board, and roll again lengthwise. Why does it not
raight line now? Raise the end of the board, and roll
ıcline observing velocity at top and bottom. Did the ball
increase its own velocity?

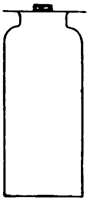

Fig. 51.

ıaw of Motion. *A body at rest tends to remain
ıd a body in motion tends to remain in motion
ırm velocity in a straight line.*

ırcely necessary to define motion and velocity, the one
ge of place, the other the rate or the rapidity of the
hat we may know the velocity, we must know (1) the
ıversed, and (2) the *time* which elapsed while the body
over the distance. If the velocity was not uniform, this
e average velocity. We shall consider bodies moving

rm velocity (as sailing-vessel before steady wind, train
tions, etc.).

rmly accelerated velocity (as a falling body).
rmly retarded velocity (as a body shot vertically upward).

Velocity is estimated in centimeters per second, meters per second, feet per second, miles per hour, etc. We know of no body absolutely at rest. Our own sun, the center of the solar system, is known to be in rapid motion, carrying the entire system with it. Rest then is relative. A body "at rest" upon the equator of the earth is at rest *relative* to the soil about it, but it is moving eastward (because of the earth's rotation), with that soil about 1,000 miles per hour. Nor is this all: the body is moving about 19 miles per second (*anti-clockwise looking south*) with the earth along the earth's orbit. It has a third motion with the solar system of roughly 16 miles per second. How many "other motions" it has we do not know, but we have every reason to suppose that these three are only a few of them. Of course with reference to any fixed portion of space, there is only one resultant line of motion over which the body moves. This is a very complex curve.

Momentum (plural, momenta) is the quantity of motion, and is measured by the product of the mass into the velocity.

A weight of 2 kilograms moving 5 meters per second has the same momentum as a weight of 5 kilograms moving 2 meters per second.

A **force** may now be defined as that which tends to produce, to change the direction of, or to destroy, motion.

Nothing but a force can do any one of these three things. If any one of these is being done, we know that a force is present. Motion is being produced, not only when a body at rest is being set in motion, but when the velocity of a body *already moving* is being increased. Motion is being destroyed when the velocity of a moving body is being decreased even though the body be not brought to rest. It is impossible to "push" without having something to push. It is impossible to "pull" if there is no resistance to the pull. Just as we say colloquially that it "takes two to make a quarrel," as in history we learn that two armies must be present for a battle, so the presence of a force implies the presence of two bodies. The resistance to the action of this force is itself *with reference to the* *given force* another force present. To avoid confusion, however, one should always be thought of as **the force** and the other as **the resistance.**

Exp. 83. — Stick a tack horizontally into a piece of hard wood, and push with a hammer against it. Strike the tack a blow horizontally with the hammer. **Percussion** or pressure is more effective in overcoming resistances such as that offered by a nail that is being driven?

(*b*) Throw a "return ball" (ball fastened to elastic cord) horizontally, and observe at what instant it "begins to pull."

(*c*) Pull up by a stout thread over a cylindrical support a pound weight *W*, Fig. 52. Place below it, stuck firmly into wood, an erect tack. Fasten the cord holding weight at the *height* of one foot. Does the weight possess any ability, if unopposed by the thread, to overcome the resistance which the tack offers to being pushed into the wood? Cut the thread quickly with scissors just above *W* and see.

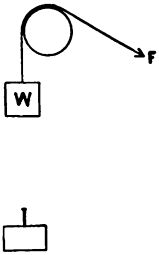

Fig. 52.

Energy is the ability to overcome resistance. A body in motion possesses energy. If the moving body meets no resistance, it is exerting no force, but whenever we **transfer the energy** of a moving body (as of a hammer) to another body (as a nail), **force** is immediately developed.

When a moving body collides with another body, part, at least, of its energy is transferred to the other body, and in the transfer force ("pushing") appears. When a "return ball" is moving freely, energy but no force is present. The moment the motion is checked by the elastic cord, force ("pulling") appears. The energy of the moving ball is transferred to the cord. How do you know that any energy is transferred to the cord?

Energy of motion, or energy actually overcoming resistance, is called **kinetic energy,** while energy due to position, as *W* in Fig. 52, or energy due to stress, as a bent bow, is called **potential energy.**

A bullet shot vertically upward has no energy before starting. Its energy is all kinetic as it leaves the muzzle of the gun. Half way up its energy is half kinetic, half potential. At the instant of reaching the highest point its energy is all potential. On the return its energy is part kinetic, part potential. At the moment of striking the earth its energy is all kinetic. A moment afterward it has no energy (mechanical) [see sources of heat] whatever, either kinetic or potential, but has expended it all overcoming resistance in penetrating the earth.

The subject Energy will by no means be completed in this chapter. Indeed, **Physics** may perhaps be best defined as the science which treats of **matter as a vehicle for energy.**

Exp. 84.--Arrange a parallelogram as in Fig. 53 with erect post *E*. Bore a small hole straight through two *elastic* balls of equal diameter (from one to two inches), and string them upon stout threads *t* and *t'* drawn taut by means of plugs *P* and *P'* set in triangular piece of wood fastened firmly to top of erect post. Take care that the parallelogram is exactly level. Place a third ball *A* at the base of the post, so that when ball on *t'* is dropped it just touches and drives *A* towards *B*, also when ball on *t* is dropped it drives *A* towards *C*. Each moving ball possesses kinetic energy, which is instantly developed into a pushing force on meeting resistance from *A* Drop both balls from the same height at the same instant, and in what direction does the ball *A* roll Load one ball with thick "open washer" of lead (Fig. 54), and drop so that the two strike ball *A* at the same instant. Transfer washer to the other ball and drop as before. This experiment should be carefully studied. [Make post *E* heavier than shown in cut.]

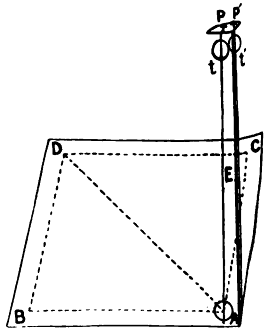

Fig. 53.

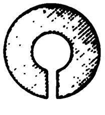

Fig. 54.

Second Law of Motion. *Every force has its full effect in its tendency to produce momentum along its own line of direction.*

The line along which any given force tends to produce momentum is called its "**Line of Direction.**" In Exp. 84 the line of direction of the first force is *AB* and of the second force *AC*. The effect produced by two or more forces acting together is called the **resultant.** For instance, *AD* is the line of direction of the resultant when the two forces are equal. The figure *ABDC* is called the **parallelogram of forces,** because for any two forces acting on lines of direction at an angle with each other such a parallelogram may be constructed in which the sides represent the direction and magnitude of the respective forces, and the diagonal the direction and magnitude of the resultant. If the forces act upon a body free to move, this parallelogram will also represent the **velocities** or the distances traversed. We may measure a force by means of a spring balance, which, when used for this purpose, is called a **dynamometer** (force-measure).

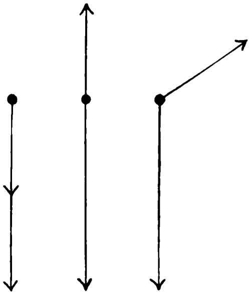

Fig. 55.

Exp. 85. — Suspend a heavy weight (iron ball or brick) by a long cord. Fasten two loops of thread, one quite long, one short, to the cord close to the weight. Attach two dynamometers. Pull in the same direction horizontally till one indicates, say, 8 units of force and the other 6 units. Cease pulling with one and, taking care that the cord as shown by some convenient indicator, is kept at the same angle with the vertical, note the reading upon the other dynamometer. (*b*) Repeat with dynamometers, pulling in precisely opposite directions. (*c*) Repeat with dynamometers, pulling at various angles, keeping angle of the cord constant with the vertical as shown by indicator. [Fig. 55 illustrates three positions of the dynamometers.]

When two forces act along the same line of direction, and in the same direction, the resultant is their *sum.*

When they act along the same line of direction, but in opposite directions, the resultant is their *difference*, and its direction is that of the larger force. When they act at an angle with each other, the resultant is *less* than their sum and *greater* than their difference, and its direction is nearer that of the larger force than that of the smaller. The forces with reference to the resultant are called **components**. Often the resultant with certain conditions is given to find the components. This is done by a reverse process of plotting from that shown in Fig. [illegible]

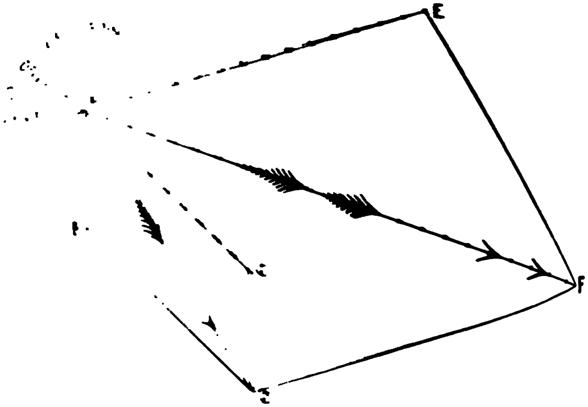

Fig. 56.

EXAMPLE 1. To find the resultant when three forces *whose lines of direction lie in the same plane* act upon a body.

Let *A*, Fig. 56, be a post against which three *pushing* forces act horizontally, the first a force of 50 kilograms. Anti-clockwise from this at an angle of 45° with the first line of direction, a second force of 100 kilograms acts, and anti-clockwise again, at angle of 60° with the second line of direction a third force of 150 kilograms acts. What is the resultant tending to break the post, and (*b*) what is its direction? Fig. 56 ought to explain itself. Measure the final resultant (double wed), using your unit of measure, a scale of 10 kilograms to the ter or to the half inch, and reduce to *kilograms*. Measure its e anti-clockwise from *AB*, the line of direction of the first force tioned. Give these as your two answers.

OTE. — Forces *acting in one plane* will be the only ones consid- in the problem work of this chapter.

Vhen three forces act, find the resultant of two of them, then compound this first resultant as though it were ngle force, with the third force. This gives a final re- ant, which is the common resultant sought. Proceed similar manner when more than three forces act.

small school square and sharp-pointed, hard lead pencil should sed in plotting. If students understand trigonometry, they may k these problems with accuracy. The *plot*, however, shows the hod, and is sufficiently accurate for the purpose of mastering all le applications of the principle of the *composition of forces*. If miscalculate the direction of your final resultant so that in plot- it runs off your paper, simply lay under the edge of the first t a second, and run the resultant off upon it as though the two ts were one. Use large units for your scale, covering the whole t with the plot, and thus increase the accuracy of your work.

xp. 86. — Arrange above a large piece of smooth paper upon the e three dynamometers pulling upon a central ring, Fig. 57, held by stout threads passing round pegs (not shown in cut). ten threads by turning pegs till gisters 12 units and *D'* 16 units orce. What does *D''* register? w lines on paper along threads ched to *D*, *D'*, and *D''* to center ing, completing after remov- dynamometers. Draw paral- ram, finding by careful plot unt and direction of the result- f the two forces acting through d *D'*. Compare with the force ted through *D''*, and with the tion of this force. If any one e three strings should be cut while the dynamometers are regis- g, what would happen to the ring?

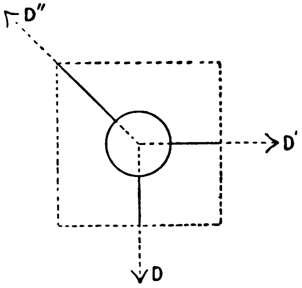

Fig. 57.

An **equilibrant** is a force acting upon a body equ and opposite to the resultant of all other forces actin upon the body. The body thus acted upon remains a rest, and is said to be in equilibrium. The resultant of *all* the forces acting, including the equilibrant, is of course 0.

Exp. 86. — (*b*) Fasten two dynamometers to the ends of a graduated stick, and another to the center, as shown by D, D', and D'', in Fig. 58. Stretch the springs of the dynamometers by means of stout threads, as in the last experiment. Add together the units of force registered by D and D', and compare with the registration of D''. What do you learn about the resultant of two parallel forces acting in the same direction? If the forces are equal, where must the equilibrant be applied?

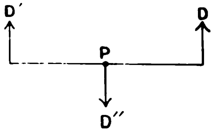

Fig. 58.

(*c*) Drive a wire nail against the center of the stick opposite D'', and remove D''. We speak of the resistance of the nail as its **reaction.** There is no motion produced by the two forces still acting, consequently there is still an equilibrant applied. What is it? Cut thread, holding D' to the stick.

Note. — Only cases in which the force acts in a plane perpendicular to the axis of rotation will be considered.

The tendency which a force has to produce rotation about a given axis is called its **moment.** The *perpendicular* distance from this axis to the line of direction of the force is called the **arm** of the force, and the product of the force into its arm *measures the moment* of the force. If the tendency is to produce rotation *clockwise*, the moment is said to be positive, if *anti-clockwise*, the moment is said to be negative.

— Arrange *D* and *D′*, Fig. 59, so that they act upon the in opposite directions with refer- plane (but in the same direction ; to rotation either clockwise or se). If now a force be applied ie springs of *D* and *D′* horizon- ich side of *P* must you drive the prevent motion? Try it. Can motion by driving two nails? with reference to *P* and on which side of the stick e best place to drive them? Can you apply any *single* hat will prevent motion?

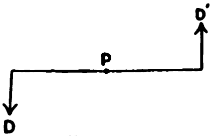

Fig. 59.

◆

e is produced when two equal parallel forces, whose lines of direction are parallel, act in lirections upon a body. The tendency of orces is to produce rotation about an axis. equilibrant can be applied. [See Fig. 84 and]

— Rule a line a little more than a meter long upon the a wire nail erect at the center Against this nail place the meter stick (or other graduated dynamometers as shown in ply forces, but keep the stick m as shown by the line. Observe of force units on each dynamometer.

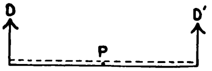

Fig. 60.

he stick along till the two arms are respectively 60 and rs long. Apply force to each dynamometer by means issing round pegs and *at right angles* to stick. Pre- uilibrium of the body (stick). Read the registration s. Multiply the force units shown on *D* by its arm, e units shown on *D′* by *its* arm, and compare pro-

(c) Slide stick, and with nail at middle point pull *one* dynamometer and at right angles to stick on the o gives the greater registration? Why?

(d) Apply *two* dynamometers on one side of the na the other side, all pulling in the same direction. products (*moments*) on the one side, and compare wit on the other side.

With respect to two or more forces acti body free to rotate, the body is in **equili** *respect to rotation* when the sum of the mo the forces tending to produce rotation in o is equal to the sum of the moments of al tending to produce rotation in the other dir

If a body acted upon by a force or by unbalanced keeping any given line in the body always parallel motion *in distinction* from rotary motion is called **Mo lation.** Rotary motion may be of two kinds: ro when the body rotates about an axis within itself, a when it rotates about an axis outside itself. In astr and revolution are sharply distinguished.

Exp. 89. — Arrange an apparatus (Fig. 61) to do th *at the same time:* (1) to *B* horizontally, and (2) to ball *B′* of equal size and w as the two balls strike the ences?

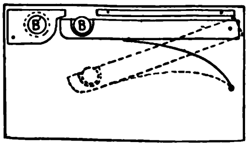

Fig. 61.

Does a force, in this "have its full effect in pro tum along its own line o the body it acts upon is already in motion? If it act on a body free to move, *after* another force has act while another force is acting? Are *all* the effects the forces act simultaneously or successively?

An upright post would be broken by a force of 200 kilograms applied horizontally at the top. Two forces are so applied simultaneously but in opposite directions, the first of 80 kilograms, the second of 220 kilograms. Effect? Effect if they are successively applied?

From the southwest corner of a smooth, level, square court laid out "upon the points of the compass," two boys kick horizontally a foot-ball. The first boy kicks precisely hard enough to send the ball, if he alone kicks perpendicularly, to the north line of the court. The second boy kicks precisely hard enough to send the ball similarly to the east line. They kick the ball twice, the first time simultaneously, the second time successively, each *in his own* direction. In what respect was the "effect" the same each time, and in what respect was the "effect" different?

When two or more forces act upon a body the order of the action of each modifies very materially the effects. It is scarcely necessary to say (you have seen the experiment performed so many times) that the effect of a given force is greater *as the time of its action is greater.* The expansive force (tension) of the gases from exploding gunpowder will throw the bullet from the rifle farther than from the revolver. This is principally because this expansive force acts longer upon the bullet before it leaves the barrel of the rifle than upon the bullet in the revolver.

Exp. 90. — Place four elastic balls (ivory, celluloid, agate, etc.) from 3 to 5 centimeters in diameter at the bottom of a curved ball-track (Fig. 62), and roll another down against them. The first ball (the ball rolled) "*acts*" upon the second, and the second "*reacts*" upon the first, stopping it. Why does not the second move? Why does the last move?

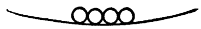

Fig. 62.

(*b*) Suspend a can of water (Fig. 63) having large vent on top, and stopped orifice *O* in one side, by a long thread. Place a convenient indicator *S* at bottom to indicate the ve cal. Remove stopple, and leave can free to move in vertical plane in which the stream of water runs. moves opposite from the direction in which the w emerges. Why? [Think carefully, for this experi would work in a vacuum.]

(*c*) Blow into tube *f* of the "reaction wheel" (Fig.

(*d*) Repeat (*a*), placing a lead ball at the center.

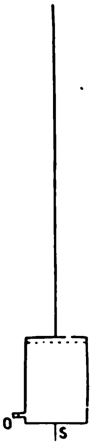

Fig. 63.

Third Law of Motion. *Reaction is equ action, and in the opposite direction.*

Exp. 91. — Upon a smooth, level board fast upright strip of hard wood for a reflector (Fig. 64). Fasten two narrow strips forming "ball-track" from *A* nearly to *B*, so that the ball may almost touch the level board. At *B*, where the line along the center of the "track" would touch the reflector, erect the perpendicular *PB*. Roll three balls succes having respectively little, more, and most elasticity (lead wood, ivory), giving to each the same and rapid velocity up track. Observe angles *PBR*, *PBR′*, and *PBR″*. These are *angles of reflection*. *ABP* is called the angle of *incidence*.

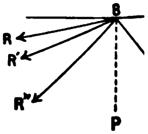

Fig. 64.

(*b*) Throw a rubber ball obliquely against the smooth flo allel to the wall.

For perfectly elastic material [that is, materia would give back promptly and without loss by m lar friction all the energy used in compressing i should have the following **Law of Reflection**: —

The angle of incidence is equal to the angle of tion, both lying in the same plane perpendicular **reflecting surface.**

Exp. 92. — Fasten a 50-gram weight to an elastic cord, and to a fine thread also. Holding firmly by the cord and lightly by the string (with other fingers), whirl horizontally, keeping the hand as still as possible. Time the number of whirls with watch or pendulum, after they have become regular. Measure by stretching the cord to same extent with dynamometer the force exerted to prevent the 50-gram weight from moving in a straight line.

(b) Whirl again, doubling the velocity. Measure force. Is the force necessary to prevent the weight from moving in a straight line double or more than double what it was before?

(c) Double the length of the cord and swing again, with one-half the angular velocity.

(d) Repeat (a), using a 100-gram weight.

The force acting on the concave side of the curve to compel a moving body to follow the curve instead of a straight line is called **Centripetal Force.** The resistance which a moving body offers to a centripetal force is called **Centrifugal Force.** These forces vary as the mass of the moving body, as the square of its velocity, and inversely as the length of the radius of the curve. These two forces are equal and opposite. If one is thought of as the action, the other is the reaction. If one is *the force*, the other is *the resistance.*

The earth is turned from a straight line to its orbital curve by the centripetal force, mutual attraction between the sun and itself. A constant or a continuous force acting upon a moving body in any other direction than along the line of motion (with or opposite in direction to the motion) causes the moving body to describe a curve. As an example we may observe a body thrown horizontally. If thrown vertically upward or downward there is no curve, as the constant force, weight, acts along the same vertical with or against the projecting force.

Exp. 93. — Revolve rapidly a flexible hoop by means of a string wound round the spool *a*, Fig. 65, to which the hoop is fastened, the whole being supported by the axis *b*.

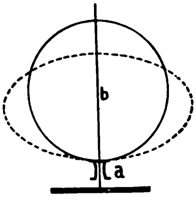

Fig. 65.

(*b*) Place a little water in the bottom of a "round" flask. Fasten the stopple in firmly with copper wire. Suspend to vertical axis (of siren) from center of stopple, and revolve rapidly. Why does the water flow up to the central zone of the bulb?

The earth's equatorial diameter is greater than the polar. Can you suggest an explanation?

The surface of the Gulf of Mexico is about 2½ miles farther from the center of the earth than the surface of Lake Itasca. *If we define up as "direction from the earth's center,"* then the Mississippi River flows "up hill." But with reference to running water, water-levels, railroad beds, etc., this is the wrong definition of the word "up." Direction above the sea-level of the parallel of latitude is "up," and below the sea-level is "down," that is, the sea-level is the 0 curve for upward and downward measurements with reference to water-levels. The surface of Lake Itasca is several hundred feet above the sea-level of its parallel of latitude, while the surface of the Gulf of Mexico is only a very few feet above the sea-level of *its* parallel, therefore, the Mississippi River does *not* flow "up hill," but flows down hill several hundred feet. [See gyroscope rotation, planetary orbits, motion, etc., in larger works, and in cyclopædia.]

QUESTIONS.

1. Why does beating a carpet free it from dust? (*b*) Why do we stamp our feet to get snow or mud off?

2. Why can we drive on the head of an ax by striking the end of the handle against a log?

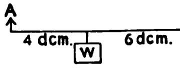

Fig. 66.

3. Two horses *A* and *B* are attached to an "evener" one meter long, as shown in Fig. 66. What part of the load *W* does each horse pull?

4. Give five illustrations of some effects of inertia that you have observed.

5. What good does it do for the boy to dodge when he is closely pursued?

6. What do you notice when you ride in the cars round a sharp curve? Explain.

7. Is there any truth in the saying of the old joke, "It isn't the fall that hurts, but the stopping so quick"?

8. Shoot an arrow from the rear platform of the train, directly backward, with the same velocity as the train has. What becomes of the arrow?

9. Why is a "running jump" longer than a "standing jump"? (*b*) Can you jump farther from a small flat rock lying in the mud flats, or from a large flat rock similarly placed? (*c*) Suppose one is standing quietly upon a "spring board" and immediately jumps, can he make as good a jump as he could from the solid ground? (*d*) Under what circumstances and *at what moment* can he make the best jump from the "spring board"? Explain.

10. The resultant of two forces acting *at right angles* is 500 kg. One of the components is a force of 300 kg. How great is the other component?

11. A cow and a goat tied to the same stake pull respectively 60 kg. and 20 kg. at an angle of 45°. What is the direction and amount of the resultant?

12. A bar 10 ft. long, supported at each end, sustains a load of 100 lbs. Where must the load be hung that one support may sustain 65 lbs. and the other 35 lbs.?

13. Explain how the sportsman shoots a rapidly flying bird?

14. Four boys pass ball upon the deck of a steadily moving steamer, the wind moving in the direction of the arrow (Fig. 67), with the same velocity and in the same direction as the steamer. They pass the ball around the parallelogram in the order of the letters. Must any of them allow for the motion of the steamer in throwing the ball? Why or why not?

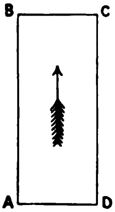

Fig. 67.

15. How would you throw a ball from a rapidly moving train, that one upon the ground could catch it without changing his position?

16. The top of a tall tower or the bottom moves eastward with greater velocity? (*b*) A ball dropped in still air on the south side of a tall, solid stone tower would strike the earth slightly north, and very perceptibly east, of the vertical line. What two forces contribute to this result?

17. A rope hung from a hook above sustains a weight (tension) of 50 lbs. What tension would the rope have if two men, one at each end, pull horizontally with a force of 50 lbs. each?

18. What effect upon a boat if a man blow against the square-rigged sail with large bellows fastened at the stern? (*b*) If he blow "straight backward," drawing in air through large valve below?

19. Which has the greater momentum, a mass of 100 kg. moving at the rate of 50 m. per sec., or a mass of 60 kg. moving 90 m. per sec.? (*b*) As "reaction is equal to action," which has the greater momentum, the bullet or the rifle from which it is shot? Why has the rifle so little velocity? Exactly what is the velocity of the rifle compared to that of the bullet?

20. If the earth's rotation could be stopped without any other effect, how would it affect the weight of bodies at the equator? At the poles? (*b*) Could the rotation cease, how would it effect the depths of the ocean at the equator? At the poles? (*c*) For what *two* reasons is the weight of a body less at the equator than at the poles?

21. Why do we not perceive the rapid motion of the earth as we do that of the express train upon which we travel? (*b*) How, then, do we know that the earth moves at all?

22. Define force, energy, moment, component, resultant, equilibrium, arm, centrifugal force, tendency, reaction.

23. Some authors use weight and "gravity" as synonomous terms, are they really so? Is the weight of a body more or less than the *measure of the* mutual attraction between the body and the earth, both taken at the latitude of 38° N.? Taken at the equator? At the poles?

24. Give two "substitute experiments:" (*a*) one a good selection from some other book, and (*b*) one of your own devising.

25. Mention two cases in which the comments of this chapter exceed the proof which the experiment offers, and (*b*) three cases in which the experiment suggests to you other and further comments.

26. Two bodies have the same momenta, one weighs 25 lbs., the other 75 lbs. The velocity of the second is 300 ft. per second. What is the velocity of the first?

CHAPTER VII.

WORK AND ENERGY.

EXP. 94. — **Stand a foot rule vertically upon the edge of the table: hold a pound weight beside it, the bottom of the weight at the level of the table. Raise the weight slowly and place it on the top of the ruler.** (*b*) **Repeat, using meter stick and kilogram weight instead of foot rule and pound weight.**

Work is *overcoming* **resistance.** When a force acts through space, that is, *overcomes* resistance, work is done. If the resistance is merely balanced, and the force produces no motion, no work is done. When you merely hold a weight you are doing no work, though in the general literary and physiological sense it may be "hard work" to hold it. When you raise the weight, however, you do work. A body that is moved is said to have work done upon it, while the body that moves another is said *to do work.* Steam confined in the boiler of an engine is doing no work, though it may be pressing ever so hard against the resisting iron shell which confines it. The moment, however, the steam is let against the piston, *so as to produce motion*, that is, so as to *overcome* resistance, it does work.

The swinging bat transfers a large part of its energy to the ball. The moving ball possesses energy because of work done upon it by the bat. The coiled spring possesses energy because of work done upon it in winding it up. The clock-weights possess energy because of work done upon them in raising them from the lowest point. They will give back again this energy in descending, and do work upon the clock.

Work and energy stand in the relationship of cause and effect. Bodies possess energy because of previous work done upon them. If more work has been done upon the body, it possesses more energy; if less work has been done, it possesses less energy. Manifestly, a unit which will measure work will measure energy.

A **foot-pound** of work is the work necessary to overcome the weight of one pound through a vertical distance (space) of one foot. How much work did you do in lifting the pound weight one foot? If you had raised a ten-pound weight five feet high?

A foot-pound of energy is the energy that must be *expended* to do a foot-pound of work, or it is the energy capable of doing a foot-pound of work.

The **kilogram-meter** of work is the work necessary to overcome the weight of one kilogram through the vertical distance (space) of one meter.

A kilogram-meter of energy is the energy that must be *expended* to do a kilogram-meter of work, or it is the energy capable of doing a kilogram-meter of work.

Notice that in measuring work there are two things to be considered: the *resistance* and the *distance* through which it is overcome. In measuring energy there are two things to be considered: the *force* and the *distance* through which it acts.

xp. 95. — **Tie a stout thread to the kilogram weight. Pass the ead over a pulley (round piece of half-inch board, with wire nail ven through the center, with drop of oil on nail), d pull straight downward till weight is raised one eter. Pull horizontally, and raise weight (overcome esistance) as before. Pull obliquely over the pulley t different angles. Omitting weight of the thread, friction of pulley, etc., how much work do you do in each case, if you raise the weight one meter? Does it matter in what *direction* the force moves in overcoming the resistance as to the work done or the energy expended?**

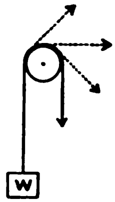

Fig. 68.

If we let **W, R,** and **S** represent respectively the work, the resistance, and the distance through which resistance is overcome, we have

$$\mathbf{W = R\,S.}$$

If we let **E, F,** and **S** represent respectively the energy, the force, and the distance through which the force acts, we have

$$\mathbf{E = F\,S.}$$

In all contracts for the doing of work, or for the delivery of energy, the "element of *time*" is an important consideration, that is, the **rate** of doing the work, or the *rate of expenditure of the energy*. If a farmer had hundreds of acres of land to be plowed, he manifestly would not enter into the contract, paying so much money to have the land plowed, without knowing whether, for instance, the contractor would be six days or six years in plowing it. The *rate of expenditure* of the energy in plowing would be of the utmost importance. So, were a man to build a large, fine house, he would want to know whether the contractor would be twenty-five days, or twenty-five years, in building it.

Power is the ability to expend energy at a certain rate. The only unit for the **rate of expenditure** of energy which will be considered in the mechanics of this book is the horse-power.

A **horse-power** is the power which can do foot pounds of work per minute (or about [illegible] meters of work per minute.

NOTE.—It may be well to anticipate somewhat that be made clearer under heat. In transferring energy to work as explained in this chapter, it is impossible to a some useless work, as in driving mills, part of the ener turned into useless heat. No energy can be lost absolu but only so far as useful work is concerned.

QUESTIONS.

1. How much work is done in raising [illegible] kg. [illegible] m. w

2. How much energy would be required to raise [illegible] m. of water weighs 1 metric ton, or [illegible] height of [illegible] m.?

3. How long would it take a two-horse-power e [illegible] kilogram meters (kg m.) of work?

4. How many kg m. of energy will be required to ra [illegible] m. long × [illegible] m. wide × 4 m. deep to the heig

5. How long will it take a 600 horse-power engine to f [illegible] m. × [illegible] m. × [illegible] m., provided the orifice of the pipe of the reservoir is 30 m. above the constant head of supply? [Allow nothing for friction in pump and loss due to "velocity of discharge." See next chapter.]

6. What is the potential energy of the water in a [illegible] m. × 50 m., provided water is at an average [illegible] m. above the sea level? (b) What energy (kinet expended in running to the sea? (c) Can potential ene expended so long as it remains such?

7. An engine of how many horse-power would be re a reservoir 60 m. × 50 m. × 40 m. in 166⅔ hours, provide of discharging orifice is 25 m. above the constant level of supply?

8. A pile-driving hammer weighing 1,500 lbs. falls much work does it do upon the pile? Is any energy "l

ssly heating both hammer and pile? Why is "lost" in quotaion marks?

9. What will be the *rate of expenditure* of energy should the ake of Question 6 descend to the sea in 30 minutes?

10. A bow unbending shoots an arrow weighing ¼ of a pound irectly upward to the height of 60 ft. How much energy was tored in the bent bow? What kind of energy was it?

11. Compare the momenta of a 10 kg. wt. moving 300 m. per sec. nd a 20 kg. wt. moving 200 m. per sec.

12. An engine of how many horse-power would be required to fill, in a half-hour, a reservoir 20 m. × 10 m. × 5 m., the reservoir being 25 m. above the surface of the supplying lake? [Theoretically.]

13. Provided 25 per cent is lost to the useful work in friction and through the "velocity of the discharge," how long would a 20 horse-power engine be in filling the last reservoir?

14. What energy raised the water from the ocean into the lakes?

15. What is the difference between force and energy?

CHAPTER VIII.

UNIFORMLY ACCELERATED AND UNIFORMLY RETARDED MOTION. FALLING BODIES. ENERGY AND VELOCITY.

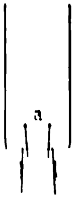

FIG. 69.

EXP. 69. Cork up a stout wide-mouthed bottle, and cutting a circular piece of tissue paper a little smaller than the cross section of the neck of bottle, drop the corked bottle and the tissue paper from the height of 5 dcm. to the table. Let the bottle fall cork downwards. Which falls more rapidly? Remove cork, and inserting four pins as shown in Fig. 69, place the tissue paper *a* upon the pins and reinsert the cork. Drop again, watching carefully to see if the tissue paper fails to keep up with the pins. (2) Hold a horse shoe magnet vertically, and drop a fine needle upon it. Drop the needle *from the same height* upon the table. It falls faster or not so fast upon the magnet?

Under the influence of weight alone, bodies *at a given place* fall with equal velocities, *regardless of their densities.* Bodies fall faster at the poles than at the equator, because their weight is greater there. [See also Chapter VI., Question 23.]

Bodies falling in the air are not under the influence of weight alone, but the resistance of the air opposes their motion. For instance, of two globes having equal weights that which has less density (and therefore greater volume) meets with greater resistance from the air. As each globe at the same height has the same potential energy to expend, the less dense globe falls less rapidly. Of two globes having equal volumes that which has greater density will fall more rapidly, because at the same height its potential energy is greater, the resistance to be overcome being the same. A one pound iron globe has *more than half* the surface of a two pound iron globe (of same density). Which would fall more rapidly in still air? Consider carefully energy and resistance in your answer.

Note. — Weight with reference to a falling body will be treated as a *constant force* in this book. The resistance of the air, unless otherwise mentioned (or inferred from a question), will be considered 0. The velocities of slowly moving bodies of great density are affected only very slightly by the resistance of the air.

Exp. 97. — Drop an elastic ball from a height of one decimeter, and reflect motion by reflector at angle of 45°, allowing ball to roll on a smooth level table against an obstruction that will suddenly stop it. Count carefully "one," "two," "three," as you respectively drop, reflect, and stop the ball. Does the ball drop farther or roll farther in the same time? Be sure about this. Why does it roll at all?

Exp. 98. — [To be performed and reported by two careful boys of the class.] Attach a stout thread to a ball and tie a loop over an open screw eye fastened in movable block of wood, so that the thread shall be a little less than a meter long. Hang the block up and adjust length of thread so that ball, swung in short arc, shall swing 60 times in one minute by the watch, that is, once every second. Procure a ladder about 7 meters long. Hang seconds pendulum against the side of the house just at one side of the foot of the ladder. Let both boys, one above, the other below, count out loud the vibrations of the pendulum, the accent with voice coming exactly at the end of the pendulum's "stroke." Let a heavy ball be dropped by boy on ladder when "*eleven*" is counted, and let the lower boy alone count "*twelve.*" Let the ball fall on a piece of hard wood. When the click of the ball and the count "twelve" come exactly together, measure the vertical height over which the ball has fallen. Let the experiment be performed when there is little wind. How far in your latitude will a body fall in *one* second?

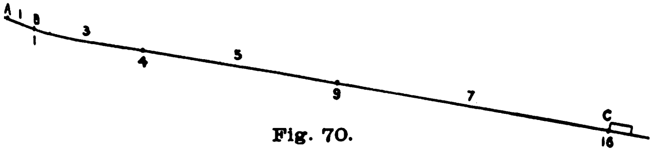

Fig. 70.

Exp. 99. — Incline a smooth board about 16 decimeters long by raising one end about 4 decimeters (Fig. 70). Draw a line across the board at *A* and another at *B*, 4.9 double-centimeters below upon the plane, *AB* being your *unit* of distance or space. Let a smooth heavy ball roll from a state of rest at A, till it strikes a heavy hard obstruction at C. Count "one" when the ball is released, "two" when it reaches B, and so on regularly, arranging obstruction at C so that "five" may be counted as the ball strikes it. Let the time required to pass from A to B be your unit of time. Mark upon the board the spaces passed over in equal times by the ball as it moves with uniformly accelerated velocity down the plane. The ball moves urged by a constant force; viz., that component of weight which acts parallel to the incline as shown by resolving the weight into its two components (Fig. 71). Only this component is effective in moving the ball as the other component is met by the reaction of the plane, and so far as producing motion is concerned is lost. Incline plane at varying angles and roll ball again. Mark off and study the spaces (Fig. 70) passed over in equal times. What do you suppose would be the relation of the spaces if you inclined your plane 90° *from* the horizontal; that is, did not incline it from perpendicular at all ?

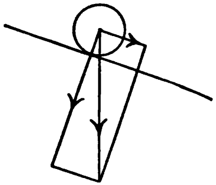

Fig. 71.

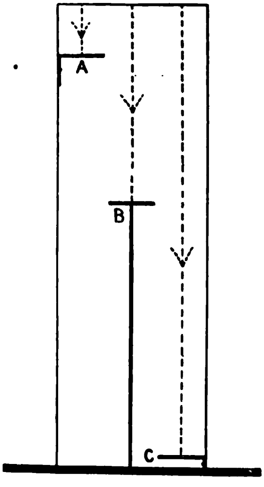

Fig. 72.

Exp. 100. — Make an upright frame of wood (Fig. 72). Let the upright parallelogram be 20 decimeters high by 3 decimeters wide, inside measurements. Let the top and side pieces be 1 decimeter wide, well joined at right angles. Let the bottom piece be of plank 6 decimeters long by 2 decimeters wide, with four flat pieces of half-inch stuff nailed beneath close to the corners for legs. In the top piece (horizontal section, Fig. 73) bore three holes very slightly larger than the diameter of the balls used in Fig. 62, the two outside spaces from center of holes being one-half as large as

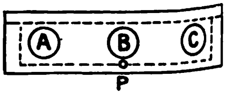

Fig. 73.

he two center spaces. Ream out *regularly* the holes, so that they shall be slightly larger below than above. Bore the hole P large enough to freely admit a lead-pencil. Arrange a trap-door on the under side of *quarter-inch* hard wood (dotted in cut), hinged by means of stout iron wire along its edge, and double-pointed tacks. Arrange this trap so that the pencil through P, striking opposite the hinge, will readily knock the trap open and release the balls. Arrange a simple catch to hold the door back as it is knocked from under the balls by the pencil. Fasten a *hard* wood platform A to the side piece, as wide as the side, projecting 8 centimeters, and, using 4 centimeters as *one unit* of space, 4.9 units of space inside measurement below the horizontal top-piece. Arrange platform B three times as far below A as A is below top-piece, and platform C five times as far below B as A is below top-piece. Place ball A in position, and knock away the trap, counting *one*, *two*, as the click of the pencil and of the ball against the platform are respectively heard. Repeat this several times till the interval of time in the *unit of time* (space of time in which ball falls to first platform) is well fixed in the mind. Now place the three balls in position, and knock away the trap. Observe if the four clicks made by pencil and three balls respectively come in regular succession. The clicks made by the last two balls are easily distinguished from those caused by rebounds, because they are successively louder. A little practice makes this a very successful experiment.

At the latitude of about 38° a body falls **4.9 meters** (16.08 feet) the first second, and acquires a velocity of 9.8 meters (32.16 feet) per second; that is, **the acceleration is 9.8 meters** per second.

In Fig. 72, if we should change the units of time to seconds, then the only other change necessary would be to change the units of space from 4 centimeters to meters; and this experiment works, except the resistance of the air begins to show itself somewhat. In studying the inclined plane (Fig. 70) it will be noticed that the space passed through during each successive unit of time is greater by a definite and constant amount, and is equal to twice the space passed through in the first unit of time. This "constant amount" is called the **acceleration.** Also it will be noticed that the space passed

Exp. 89 and others we learn that this is true even if the body be thrown obliquely. If a body rises vertically for two seconds before it begins to return, it must have the same *initial* velocity that a body would acquire in falling from a state of rest for two seconds; viz., 19.6 meters per second. A rifle bullet shot horizontally would fall to the tangent from the earth below just as quickly as though it were dropped.

Exp. 102. — Fill a receiver, having a large bent glass tube passing through perforated cork, and drawn out, as shown in Fig. 74, with water, keeping finger on orifice *B*. Remove finger, the jet from orifice rises nearly to the level of *A*. Three resistances prevent the jet from reaching *A*: (1) resistance of the air, (2) friction at orifice and in pipe, (3) the water that falling from highest point reached, meets the rising globules. The vertical distance *BA* from the center of the discharging orifice to the surface of the source is called the "**head.**" Did you ever see any one underestimate the velocity of a "spouting liquid" when the head was great?

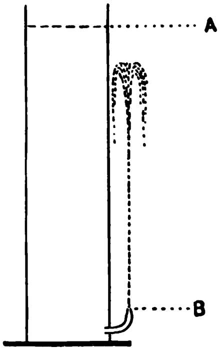

Fig. 74.

Under the influence of pressure only, the velocity of a liquid flowing from an orifice is equal to that of a *body that has fallen freely through a space equal to the head.* [See Exps. 44 and 45.]

Since we know how high a given velocity in a vertical direction will raise a body, we may measure the energy of a moving body, whose mass and velocity are known, in kilogram-meters. For instance, a body with a mass of 1 kilogram moving upward with a velocity of 9.8 meters per second, would rise 4.9 meters, just as far as it must fall to acquire that velocity. It would be one second going up and one second coming down. Manifestly it would possess

[illegible] kinetic energy. [illegible]
[illegible] kilogram-meters [illegible]
[illegible] grams it would possess [illegible]
[illegible] does not matter [illegible]
[illegible] depending on its mass [illegible]
[illegible] what space a given [illegible]
[illegible] vertically upward, [illegible]
[illegible] height) its kinetic ener[illegible]
[illegible] For the sake of sho[illegible]

[illegible] space [illegible]
[illegible] energy, we have,

[illegible] following importan[illegible]
[illegible] kilogram-meters, when [illegible]
[illegible] body given [illegible]

[illegible] obtained

from the equation $E = Kv^2$ without stopping to divide each product by 2g.

NOTE.—See Galileo, falling bodies, projectiles, miner's inch, hydraulic mining, etc., in cyclopædia. If you choose to anticipate college work, see also the absolute units dyne, erg, and the centimeter-gram-seconds (C. G. S.) system of measurements in college text-books.

QUESTIONS.

1. How far will a body fall in 1 sec.? In ½ a sec.?

2. A body has fallen 5 sec., how far has it fallen? What velocity has it attained?

3. A body has fallen 490 m., how long has it been falling? What velocity has it attained?

4. An arrow shot over a steeple reaches the ground in 6 sec., how high is the steeple?

5. A ball thrown vertically upward with an initial velocity of 49 m. per second has what velocity at the end of 3 sec.? At end of 5 sec.? At the end of 7 sec.?

6. A cannon-ball weighing 300 kg. and moving 500 m. per second has how much kinetic energy?

7. Which has the greater momentum, a 5 kg. weight moving 60 m. per second or a 20 kg. weight moving 30 m. per second? Which has the greater kinetic energy? How many times as great as the other?

8. Define acceleration, weight, kinetic energy, head, kilogrammeter, foot-pound, power, velocity, vertical, momentum.

9. A body shot horizontally from the top of a tower 176.4 m. high strikes the ground at what point, provided the velocity of projection is 100 m. per second?

10. A body shot upward at an angle of 45° with the horizon from a tower 30 m. high, with initial velocity of 20 m. per second, would be at what point at the end of the third second?

$$\textit{Ans.} \begin{cases} \text{—— meters horizontally from the tower.} \\ \text{—— meters from the ground.} \end{cases}$$

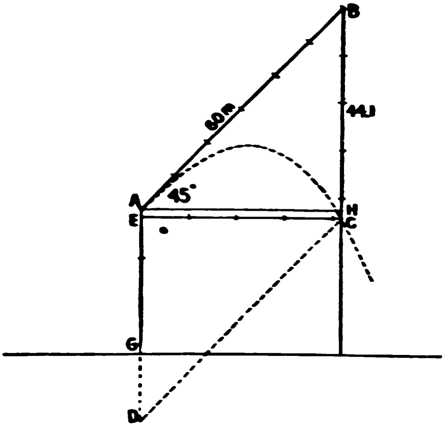

Fig. 75.

NOTE. — The path of the projectile may be found by plotting its position at the end of the 1st, 2d, 3d, etc., seconds and running the curve through these points. If greater accuracy is required, plot position for fractions of seconds. There is no necessity of plotting the "parallelogram of forces," but the effect of the two forces may be plotted successively as though the other did not act, only each must be laid off *in its own direction.* The horizontal distance passed over by a projectile before it strikes the ground is called its **range** or **random.**

11. A stone thrown downward from a building at an angle with horizon of 30°, with initial velocity of 30 m. per second, is how far below the horizontal plane from which it was thrown, in 4 sec.?

12. A 10 kg. weight has fallen 313.6 m., what velocity has it attained? What is its kinetic energy? Its momentum?

13. A body thrown vertically upward with initial velocity of 9.8 m. per second will rise to what height? How long before it will return to the level of the starting-point?

14. What will be the theoretical velocity of water flowing from a head of 78.4 m.?

15. The area of the nozzle from which an hydraulic stream issues is 1 sq. dcm., the head 122.5 m. What will it cost the owners of the hydraulic mine per day of 24 hours for water, provided they pay $.0001 (one-tenth of a mill) per cubic meter for water, and are allowed 10% off the theoretical flow for losses by friction, cross currents at nozzle, etc.? [But see "miner's inch" in cyclopædia.]

16. Are two plumb lines parallel? Why is it that some good carpenters will tell you they are? A carpenter should know what a plumb line is.

17. When a hammer is thrown why does it usually strike with the handle upward?

18. Why do drops of rain not strike with the velocity computed for falling bodies?

19. Why is sand, rather than rocks, thrown from a balloon to lighten it?

20. State and solve a problem under falling bodies, using the foot and pound as units. Compute the kinetic energy of your falling body at the lowest point in its fall in foot-pounds.

21. Could we measure with *absolute* accuracy the smallest portion of space, should we find that the earth "fell" *any* towards the apple, while the apple was falling to the earth? How would it be if *two* apples of equal masses were falling from the same height on precisely opposite sides of the earth?

CHAPTER IX.

CENTER OF GRAVITY AND STABILITY.

NOTE. — Stability in this chapter will be treated as affected by *weight only* operating against the support.

EXP. 103. — Place a knife-blade edge upward in a vise. Balance a *homogeneous* stick of uniform cross section in three different positions, with length horizontally at right angles to knife-blade, obliquely at right angles, and vertical. Place the stick again balanced in horizontal position, and mark carefully vertical plane above knife-blade. Remove, and with fine saw cut into two pieces through this plane. Place pieces one in each opposite scalepan. Are they at least nearly of the same weight?

(*b*) Balance in horizontal position an old hammer with handle, or other similar body, and saw into two pieces as before. Do the two pieces balance in the scalepan now?

(*c*) Suspend square-cornered piece of board successively from two adjacent corners as shown in Fig. 76. Mark the extension of the vertical downward in each case upon the board by means of a very long ruler applied to suspending thread.

(*d*) Support an irregular body (Fig. 77) upon a pivot, and study the figure. What does *R* mean? What does *E* mean? What do the little arrows mean?

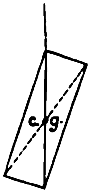

Fig. 76.

The **Center of Gravity** (c. g.) of a body is (1) that point through which any vertical plane being passed, the *sum of the moments of the weights of the particles on one side* of the plane is equal to the sum of the moments

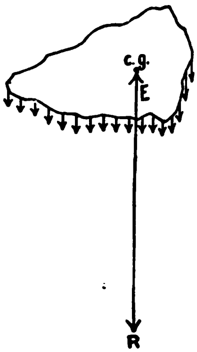

Fig. 77.

n the other side; (2) that point which lies in the plane ertically above *any* supporting base-line upon which he body is balanced; (3) that point in a balanced body vhich lies vertically above or vertically below *any* point of support, and therefore at the intersection of any two such verticals; or (4) the point of application of the equilibrant opposing the body's weight.

Exp. 104. — **Weigh a homogeneous stick of uniform cross section. Lay it horizontally upon a smooth table, so that its center of gravity shall be one decimeter from the edge of the table. Place a weight equal to one-half that of the stick upon the stick at the table's edge, and push the weight slowly towards the free end till the stick just tips (rotates about point *B*, Fig. 78). Bring the weight back a very little, so that the stick will barely remain stationary, and from your knowledge of moments of forces, comparing the arms *AB* and *BC*, what weight must be acting at *A* to balance the smaller weight acting at *C*?**

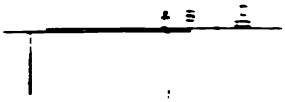
Fig 78.

The entire weight of a body taken as a unit may be considered as concentrated at its center of gravity. This enables us to find the center of gravity by a process similar to that of Exp. 104, as well as by balancing. In homogeneous bodies of the type of a ball, or square-sectioned meter stick, the center of gravity lies at the center of volume. The center of gravity is often called the "center of inertia," "center of weight," and the "center of mass." But it is important to remember that the plane through the center of gravity very rarely divides a body into two equal masses (Exp. 103, *b*). Why not?

Exp. 105. — **Balance a ring or hollow quadrilateral upon a line in several different positions. Where is the center of gravity located?**

The center of gravity of a body does not necessarily lie in the material of which the body is made, for example, that of a ring, hollow ball, bottle, etc. In certain important senses, however, in the discussion of stability (see below), a body is considered to include all the space within its outlines, and in this sense the center of gravity of an ordinary bottle is in the body.

The **line of direction** of a body is the vertical passing through the center of gravity. The weights of all the particles composing the body act downward as forces, *sensibly* parallel to this line (Fig. 77). The direction of the resultant of all these forces is downward along the line of direction, opposite the equilibrant or the "supporting force."

Exp. 106. — To find the center of gravity of two bodies considered to be connected as one by a line without weight. — Balance the square-sectioned meter stick, place a kilogram weight one decimeter from the support, and balance by a 200 gram weight opposite the support. As the weight of the meter stick has nothing to do with affecting or disturbing the balance, we have the essential conditions, so far as equilibrium is concerned, of two bodies balanced upon a line without weight connecting their centers of gravity.

The common center of gravity of two bodies (considered as one) lies along the line connecting their centers of gravity, distant from the center of each *inversely as their masses*, that is, the product of the mass of *A* (Fig. 79) into its distance from the common center of gravity is equal to the product of the mass of *B* into *its* distance from the common center of gravity.

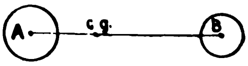

Fig. 79.

Exp. 107. — Place a cone upon the table (the supporting surce) in the three positions shown in ig. 80. Incline slightly the vertical ne in the cone (incline the right hand one towards the side) and notice whether the center of gravity is raised or lowered by the movement, and if body tends to return to its former position, or to depart farther from it, or to do neither.

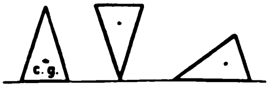

Fig. 80.

(*b*) Suspend a body and draw it slightly aside. Will it remain there?

(*c*) Take a short stick *AB*, and inserting one knife at *A*, and two knives obliquely at *B*, balance on pivot as shown in Fig. 81, incline slightly the stick on its point of support. Does the body tend to return to its former position? Do you raise or lower the center of gravity of "the body" when you incline it? Where is its center of gravity with respect to the point of support?

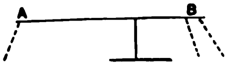

Fig. 81.

A body is in **Stable Equilibrium** upon a supporting surface when to incline its upright axis the center of gravity must be raised, or when the line of direction falls within the base; and a suspended body is in stable equilibrium when the center of gravity lies vertically below the point of support.

A body is in **Unstable Equilibrium** upon a supporting surface when to incline its upright axis the center of gravity must be lowered, or when the line of direction falls without the base; and a suspended body (or body sustained upon a point) is in unstable equilibrium when the center of gravity does not lie *at*, nor *vertically below*, the point of support.

A body is in **Neutral Equilibrium** upon a supporting surface when to incline its upright axis the center of gravity is neither raised nor lowered, or when the line of direction of the body falls upon a supporting point or line for several different inclinations; and a suspended body is in neutral equilibrium when its center of gravity lies at the center of the axis of support, neither above nor below it (as a carefully balanced wheel supported by the axis).

Exp. 108. — Place a chalk box (or other similar body) upon the table, on bottom, side and end successively, and overturn in each position. In what equilibrium is it in each position ?

There are different degrees of stable equilibrium, that is, of stability. A body is more stable (1) if its center of gravity remaining at the same height, the base is larger, or (2) if, base remaining the same, its center of gravity is lower. If both the base is enlarged, and the center of gravity lowered, the "stability" is rapidly increased.

Exp. 109. — Turn a short heavy brass screw into the small end of a cork, and float "the body" in water (Fig. 82). Remove screw, and turning it into the large end of cork, float again. What tendency do you observe as to the position of the center of gravity ? [See hydrometer, Exp. 71 (c).]

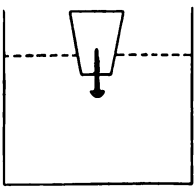

Fig. 82.

Ordinary **floating bodies** tend to carry the center of gravity at the lowest point.

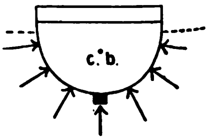

Fig. 83.

That point that would be the center of gravity of the displaced water is called the center of buoyancy (c. b.). It is the point of application of the resultant of all the pressure force lines (Fig. 83), and this resultant acts vertically upward, while the resultant of the weight force lines (Fig. 77) acts vertically downward.

Exp. 110. — Cut out a hemisphere of cork, weigh it, and float with convex side down. Upon the flat top place a heavy piece of ad, sinking the cork nearly but not quite to the water's edge. oes the loaded cork capsize easily or with difficulty?

(b) Place another very flat piece of cork of the same volume determined by weighing cork of same quality) as before upon water, and load it with the same piece of lead. Does the loaded cork capsize easily?

Note. — The stability of only two types of floating bodies will be considered in this chapter, the ocean-vessel type and the flatboat (raft) type.

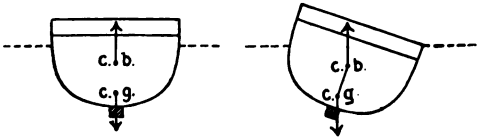

Fig. 84.

Floating bodies are in maximum stability when the center of gravity is farthest below the center of buoyancy. Fig. 84 shows that in bodies of the ocean vessel type the two forces of weight and buoyancy form a **couple** tending to right the vessel whenever it is inclined from its upright position. Floating bodies of the flatboat type (Fig. 85), may be in very stable equilibrium, even when the center of gravity is above the center of buoyancy, because when the floating body is inclined, its shape is such that the center of buoyancy "*shifts*" towards the deeper displacement. Fig. 85 shows that in this case the forces of weight and buoyancy still form a **couple** tending to right the floating body.

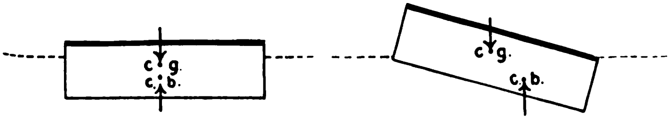

Fig. 85.

QUESTIONS.

1. Define couple, stable equilibrium, center of gravity, center of buoyancy, line of direction, homogeneous body, uniform cross section.

2. A body falls when, under the influence of its weight only, its center of gravity is lowered. What does the "witch" (Fig. 86) do when it "rises"? The "loaded disk" (Fig. 87) when it "rolls up-hill"?

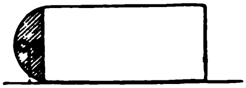
Fig. 86.

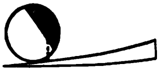
Fig. 87.

3. Which is more easily overturned upon the hillside, a ton of hay upon the cart, or a ton of stone upon the same cart? Why?

4. Why not walk across the bay with cork boots sufficiently large to sustain you?

5. Two men carry a homogeneous stick of uniform cross section 20 ft. long. *A* takes hold at the end, and *B* five feet from the other end (Fig. 88). What part of the stick does each carry?

Fig. 88.

6. The same homogeneous stick has two pieces of equal cross section with the stick, and each five feet long, fastened to the end *A* as shown in Fig. 89. Where is now the c. g. of the three combined sticks? [Exp. 106 and Fig. 79 will help you in solving this.]

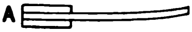

Fig. 89.

7. I weigh the same homogeneous stick, and find its weight to be 40 kg. I bore out a cylindrical hole at one end (parallel with stick) four feet deep, and fill it with lead weighing 20 kg. more than the "borings" removed. Where is now the c. g. of the loaded stick?

8. A three-legged or a four-legged stool is (other things being equal) more stable? (*b*) Why do old men carry canes? (*c*) Why do people lean to the left when they carry a heavy weight with the right hand?

9. In what equilibrium is a homogeneous ball upon a level table Upon a smooth inclined plane? A round homogeneous stick o timber upon a level surface is in what equilibrium with reference t

inclinations towards either side? With reference to an attempt to incline so as to stand the stick on end? May a body possess more than one kind of equilibrium at the same time?

10. Why does a ship carry "ballast"?

11. What would be the disadvantage were our feet as small as the dog's?

12. Ask one *good* question, of your own originating, under the head of this chapter. Ask one that you obtained from some other text book. Answer both.

13. How would you lower the c. g. of a stool?

14. How would you make a row boat less likely to capsize, that is, make it more stable while floating?

15. Why must one *learn* to "walk" on stilts and to "ride" upon a "safety"?

16. Why is it difficult to stand still upon skates?

17. Why does the teamster put on the brakes when going down hill?

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CHAPTER X.

THE PENDULUM.

Exp. 111. — Suspend two balls of lead by stout fi
(*a* and *b*, Fig. 90). Vibrate through *small arcs*, and co
"*two*," etc., to twenty as the pendulum
a single vibration. Vibrate one throu
large arc and the other through a sma
count as before.

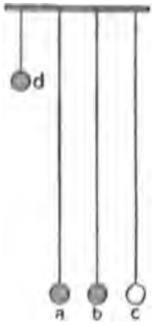


Fig. 90.

The arc of vibration being s
vibrations of a given pendulum a
place are isochronous.

Exp. 112. — Suspend a piece of cork
by string of equal length beside the p
Swing *b* and *c* together, and count as be

The time of vibration of a
is not affected by the material of which it is

Exp. 113. Shorten the string, bringing *a* to the p
till it vibrates twice, while *b* vibrates once as determi
pupils counting to twenty and ten respectively. Let
"twenty" be spoken louder than the other numbers.
length of each *approximately* to the centers of the balls.
one pendulum to vibrate twice as fast as another, how lo
make it?

The lengths of two pendulums are propo
the squares of their times of vibration at a gi
Stating mathematically, we have,

$$\underset{\text{length of one}}{l} : \underset{\text{length of the other}}{l'} :: \underset{\text{sq. of time of one}}{t^2} : \underset{\text{sq. time of the other}}{t'^2}$$

Exp. 114. — With very fine thread and small lead ball find the length of a pendulum that will vibrate 60 times in one minute "by the watch," measuring approximately from the center of the ball.

A **seconds pendulum** in latitude about 38° is **.993 of a meter** long (or about 39.1 inches).

Exp. 115. — Suspend a piece of soft iron and swing the pendulum through an exceedingly short arc. Hold a bar magnet vertically below and near the soft iron, and swing the pendulum as before, counting its vibrations each time. Does it swing faster or more slowly? How would it swing if we could increase the force of the earth's gravitation?

The time of vibration of a pendulum varies inversely as the square root of acceleration due to weight ($\sqrt{g}$). That is, a given pendulum vibrates faster at the poles and more slowly as it is brought towards the equator. Clocks regulated for one latitude would not keep good time in another latitude.

Exp. 116. — Suspend two triangular pieces of wood of precisely similar dimensions from opposite ends by means of screw eyes as in Fig. 91. Swing the two pendulums and note which vibrates in less time. Manifestly by the "length of a pendulum" is not meant the distance from one end to the other. These as sticks have the same lengths but as pendulums different lengths. The dot on each in the cut is *not* meant to represent the center of gravity of the stick, but another point near the center of gravity.

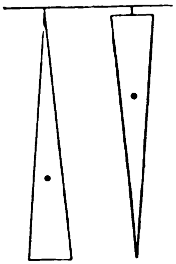


Fig. 91.

Exp. 117. — Suspend a square-sectioned stick (Fig. 92 *a*) by screw eyes, and adjust a ball *b* to vibrate in the same time. Fasten a short heavy iron clamp at *A* upon the stick, and time with the ball. Does the stick vibrate faster or more slowly than the ball?

Fasten clamp at *B* and time. Does the stick vibrate faster or more slowly than the ball now? Fasten the clamp the third time horizontally near the level of the ball's center, and adjust clamp till the stick and ball swing exactly together.

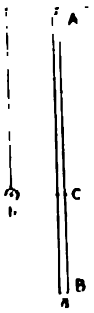


Fig. 92.

Particles near the top of a pendulum tend to move faster in the arc than the pendulum taken as a unit. Particles near the bottom tend to move more slowly. Between, upon the vertical axis of the pendulum, there is a point which tends to vibrate neither faster nor more slowly than the pendulum taken as a unit. This point is called the **Center of Oscillation.**

The **length of a pendulum** is the distance from its point of suspension to its center of oscillation.

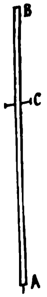


Fig. 93

Exp. 118. Mark the level of the clamp at *C* upon the stick. Suspend stick by two pins (Fig. 93) on opposite sides at this level and swing comparing with the ball. If you have succeeded in locating the center of oscillation it keeps time with the ball.

The point of suspension and the center of oscillation are *interchangeable points.*

Exp. 119. Remove the face from a small clock and study the movements of a bent piece of steel called the **escapement** *acting upon* and *being acted upon by* the "escapement wheel." Consider these three things, the coiled spring of the clock, the escapement, and the pendulum. What *double office* does the escapement fulfill? How does it "stand between" the spring and pendulum? It enables the coiled spring to do what to the pendulum? It enables the pendulum to do what to the coiled spring? What would happe to the coiled spring if you should suddenly remove the escapement What would happen to the pendulum if you should remove tl escapement?

The pendulum furnishes an excellent illustration of the change of potential energy to kinetic energy and *vice versa*. At *A*, Fig. 94, the vibrating pendulum's energy is all potential, at *B* all kinetic, at *C* all potential again. Between the lowest point and the extremities of the arc on either side, the energy is part kinetic and part potential. The force of weight *W* being resolved into its two components *a* and *b*, the component *a* is lost so far as affecting motion is concerned, being met by the reaction of the string, while the component *b* is effective in moving the pendulum. Why will not such a pendulum swing forever? The extent of the excursion on either side of the vertical is called the **amplitude** of the vibration and is measured by the angle *BSC*. The motion of the pendulum is classed among "harmonic" motions, because it is like in important respects the vibration of the prongs of the tuning-fork, the vibration of strings, etc., which produce musical sounds.

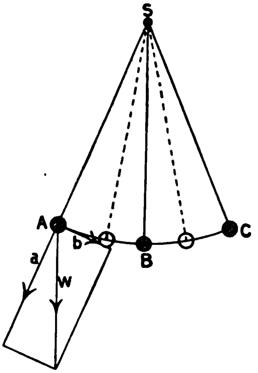


Fig. 94.

[For compensation pendulum see heat. See Foucault, Galileo, Huyghens, etc., in cyclopædia.]

QUESTIONS.

Note. — In the problem work of this chapter the **seconds pendulum** may be considered to be **1 meter long** instead of .993 meters. Having the length of your "standard" pendulum, you have two terms in the proportion ($l : l' :: t^2 : t'^2$) given and need to know only a third; viz., the length or the time of the other pendulum to find its *time* or *length* respectively.

1. Define the pendulum, seconds pendulum, length of a pendulum, center of oscillation.

2. How long must a pendulum be to vibrate once in 2 sec.? Once in ¼ of a sec.? Two times in 3 sec.? Three times in 2 sec.?

3. A pendulum 16 m. long vibrates in what time? A pendulum $\frac{1}{9}$ of a meter long? A pendulum $\frac{16}{25}$ of a meter long?

4. An ordinary pendulum clock gains or loses time in winter? In summer? What should be done if this clock gains time? If it loses time? Why is the "bob" lenticular?

5. A fine clock with compensation pendulum (length unaffected by heat), regulated so that its "rate" is a loss of 8 sec. per year at latitude 38°, would have its rate affected in what way if the clock were placed in latitude 45°? If placed at the equator?

6. Does "gravity" (weight) "tend to stop the pendulum"?

7. What takes the place of "the pendulum" in the watch?

8. What is a "jeweled" watch, or why is a watch jeweled? [See friction.]

9. How many strokes or vibrations must the pendulum make that the escapement wheel may turn round once? [A double vibration is called a *complete vibration* in distinction from a simple vibration which is called simply "a vibration."]

CHAPTER XI.

MACHINES.

ACHINE is a contrivance by which force can be
d to resistance more advantageously. The advan-
to be derived from machines may be classified
three heads. By means of machines, we may,

Exchange **velocity** of force for **intensity** of force or intensity for velocity. This is called a **mechanical advantage.**

Change **the direction** of our force; that is, the force may move in one direction, and the resistance may be overcome in the opposite, or in any other direction. The wheel and axle ordinarily gives us this advantage in addition to its mechanical advantage.

Use **other forces** than our own, as the force exerted by animals, wind, water, steam, etc.

e machines studied in this chapter will be,

The Lever.
The Wheel and Axle.

The Inclined Plane.
The Wedge.
The Screw (acted upon by lever).

VI. The Movable Pulley.
VII. The Hydrostatic Press.
VIII. The Toggle-Joint.
IX. The Hydraulic Ram.

Exp. 120. — Balance the meter stick upon a knife edge *f* (Fig. 95). Place supports just below at *S* and *S'*. Place a weight *W* (*Resistance*) of 5 kilograms, 1 decimeter, from the knife-blade (*Fulcrum*) towards *S*, and place a force *F* of 1 kilogram towards *S'* till there is equilibrium between the force and the resistance. Remove supports, and move the point of application of the force downward, and by the help of your knowledge of geometry (similar triangles) compare the distance passed over by the force *F*, and the distance through which the resistance *W* moves with the weights *F* and *W*.

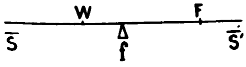


Fig. 95.

The great **Law of Equilibrium** for machines is:

Force multiplied by Force's distance (Fd) is equal to Weight multiplied by Weight's distance (Wd).

Stating by an equation, we have

$$F \times Fd = W \times Wd$$

We have only to determine some convenient ratio of *Fd* to *Wd* in each machine, and we have its **leverage,** or **mechanical advantage.** The distance through which the point of application of the force *moves* in a given time when the machine is in motion is force's distance (*Fd*), and the distance through which weight moves *in the same time* is weight's distance (*Wd*). Or the "arm" of Force and of Weight respectively may be taken fo *Fd* and *Wd* when these are evident.

There are three forms of the lever (Fig. 96), known as first class *f*, *between*), second class (*W*, *between*), and hird class (*F*, *between*). Levers may be traight or curved.

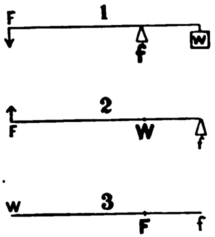


Fig. 96.

In the lever

Fd = perpendicular distance from **f** to the line of direction of **F**.

Wd = perpendicular distance from **f** to the line of direction of **W**.

Exp. 121. — Balance a heavy known weight, *W*, upon an axle by a lighter force, *F*, upon the wheel as shown in Fig. 97. Move *F* downward equal to the radius of the wheel, and measure carefully through what distance (or space) the resistance *W* is overcome.

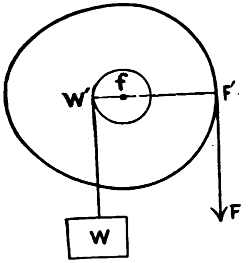


Fig. 97.

In the **wheel and axle**

Fd = the radius of the wheel (cir. or diameter)

Wd = the radius of the axle (cir. or diameter)

It will be noticed that the wheel and axle is only a disguised, continuously acting lever, *F'f* (Fig. 97), being the *Force arm* of the lever, and *W'f* being the *weight arm*. It will also be noticed that a convenient change in direction in addition to the *mechanical advantage* is secured by the wheel and axle. If *change in direction* only is desired, a form of the wheel and axle shown in Fig. 98 called a **Fixed Pulley** is used, in which the radius of the wheel is equal to the radius of the axle, that is, the wheel and axle are combined into one. Here, of course, Force and Weight are equal, and it is not necessary that the direction of motion shall be opposite. Force may act in direction *F''*, or in any other direction, by a combination of fixed pulleys

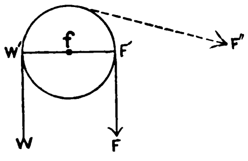


Fig. 98.

Exp. 122. — Weigh a smooth inch board (4 × 1 dcm.) with screw-eye and three balls (used in Exp. 90). Arrange a smooth inclined plane 1 meter long by 3 decimeters high. On this plane place the three balls carrying the board, two at the lower end on each side, and one at the upper end in the middle. Attach in front by means of the screw-eye a delicate dynamometer (*D*, Fig. 99), and note its registration when it is held parallel to the incline, comparing this to the weight of the load, and the two to the height and length of the inclined plane.

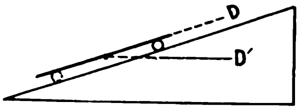


Fig. 99.

(*b*) Bore two holes through center of the inclined plane about one decimeter apart, and saw out a narrow piece between them. Attach a string through this to the screw-eye now fastened to the middle of the board below, and hold the dynamometer *D′* parallel to the base of the plane. Compare registration, load, height and base of plane.

In the **Inclined Plane**

Fd = the length of the inclined plane

Wd = the height of the inclined plane

when *F* acts parallel to the incline, and

Fd = the length of the base,

Wd = the height of the inclined plane,

when *F* acts parallel to the base.

Exp. 123 — Cut out a wedge (Fig. 100), and rule a line from the center of the back to the apex. How many inclined planes have you in the wedge, and how are they placed? Does the force of the percussion act parallel to "the base," or to "the incline"? Have you ever seen a simple inclined plane pushed along instead of driven? Where?

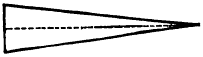


Fig. 100.

Note. — No problems will be given under the wedge, as friction and kinetic energy would enter into them so largely; and no problems will be given in which the force acts at an angle with the incline other than parallel to the base.

P. 124. — Turn a screw by means of a lever *Ff* (Fig. 101), ely once around its axis, measur- .refully the distance which *A* de- s or rises. Compare this distance he distance between the threads screw *measured parallel to its* More accurate results will be ied if the lever is turned com- y round, say, ten times, and the ice between ten threads measured. re any similarity between a screw n inclined plane? Explain.

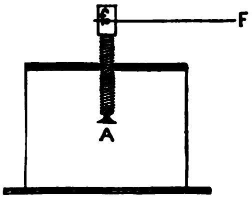


Fig. 101.

the screw acted upon by a lever:

l = the circumference described by the lever. The gth of the lever" is the perpendicular distance the line of direction of the force to the vertical of the screw.

d = the distance between the threads of the screw, sured parallel to the axis.

r. 125. — Arrange three sets of pulleys with continuous cord as shown by *A*, *B*, and *C*, Fig. 102. *E* represents one end of the cord showing attachment to the casing of the pulley and *F* the force end of the cord. Balance two weights *F* and *W* (counting weight of movable block as part of *W*), the heavier the better, so that the friction shall tell similarly against each. In each case move down *F* till *W* rises one decimeter. Compare the distance *F* moves with the number of cords which sustain the movable block. Compare also quotient of $W \div F$ with number of these cords.

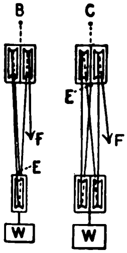


Fig. 102.

ne pulley with its casing is called the **Block.** The block which s is called the Movable Block, and the other which does not the Fixed Block. The pulleys are also called respectively fixed ys and movable pulleys. Be careful to attach the weight to the g of the movable block and attach *E* with care. The cords sus-

sustaining cords." When [illegible] the force cord pulls in [illegible] resistance is over- [illegible] sustaining cord.

[illegible] numerically).

[illegible] combinations of pulleys [illegible] sustaining, etc. [illegible] Fig. 103, in [illegible] The weight [illegible] cords, that [illegible] combination [illegible] through small

[illegible] in the [illegible] the out- [illegible] millimeter [illegible] inclining [illegible] dish with [illegible] two sur- [illegible] Measure [illegible] distance [illegible] distances [illegible] becomes the force F' proper to apply to the press, and from this as the force the total pressure W' upon the platform is found. The principle upon which the Hydrostatic Press acts is very analogous to that of the Movable Pulley. By means of the pulley we multiply "pulling" lines of force through the multiplication of sustaining cords. Our multiplication is practically limited by friction, etc. In the press through the principle of the transmission of pressure by liquids, we multiply "pushing" lines of force, and the press is nearly frictionless for any amount of mechanical advantage. *CC* are *connecting* chambers supplying liquid, and V and V' are the valves of the force pump. What is V'' used for? V'''? The arrows represent quite imperfectly the pressure in *all* directions, the *effective* pressure being upward against the bottom of the cylinder carrying platform W'. A small or portable Hydrostatic Press is called an **hydraulic jack.**

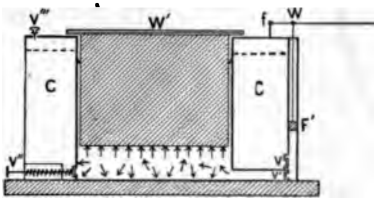


Fig. 104.

Exp. 127. — Fasten two strips of board (Fig. 105), about 4 decimeters by 4 centimeters, endwise by a slightly worn and oiled hinge. Drive a nail into the table, and lay one end (hinge downward) against the nail. Find with dynamometer how much force is required to move a brick or other heavy body upon the table. Lift the hinge h about 2 centimeters and place the brick W against the other end. Apply a weight (force) at F to move W, and compare this force with that registered on the dynamometer.

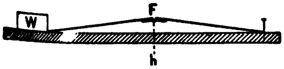
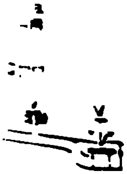


Fig. 105.

The **Toggle-Joint** is used where great force is required to be exerted through short distances. Its *form* is for convenience sometimes employed, where the principle is not required as in the buggy top. *Fd* and *Wd* varying constantly with the angle of the joint, no problems upon the toggle-joint will be given. This machine is often called simply a Toggle or a Knee.

[illegible] Arrange a supply tube S from a dish of water and a lamp chimney C as an air cha ber. With wax and pieces of gla arrange box and valve V, makin V just heavy enough bare to sink in water to the sup ports below. The proper weig may be obtained by loading i slightly on top. Let tube a ri a little higher than the surface of the supplying reservoir.



[illegible]g. [illegible].

[illegible] Hydraulic Ram [illegible] convenient machine for raising water [illegible] utilizing the kinetic energy of the flow. This is [illegible] checking of the flow (after it has attained its [illegible] valve V driven upward by the current. [illegible] open so that water enters an air- [illegible] with the tank or reservoir above. Of course [illegible] flowing in the supply pipe S can be raised, so [illegible] not make water of itself rise above [illegible] seek its level."

[illegible] adjacent sides of a brick and place it on [illegible] the incline so that the brick will just slide [illegible] Do the angles vary materially? (b) Place [illegible] first and find angle of sliding. Is it greater [illegible] Place some smooth substance between the brick [illegible] and find angle. (d) Find angle when brick is laid on [illegible] and released, and angle after brick is held still upon plane for some time. Which is larger? (e) Place on plane a piece of round molding with its longitudinal axis parallel to the incline, and then turn axis to horizontal position. Molding slides or rolls at the less angle?

Friction is the resistance offered to motion by two surfaces in contact. This is due to the roughnesses upon them, polished surfaces even not being perfectly smooth. Friction (1) within moderate limits is not affected by extent of surface, (2) is approximately pro rtional to pressure, (3) varies with the nature of the rfaces, in general being greater between like surfaces d less between unlike, (4) increases (to the maxium) with the time the surfaces have been in contact, d (5) is greater when the surfaces *slide* than when ey roll, that is, "rolling friction" is less than "slidg friction."

By the **efficiency** of a machine is meant the amount f useful work obtained from it compared with the amount expended upon it. If we do 100 kilogrammeters of work upon a machine, and 12 per cent of it is lost in useless friction (which is by far the greatest loss in ordinary machines, but see steam-engine), the efficiency of the machine is 88 per cent. Is friction ever useful?

NOTE.—See capstan, overshot wheel, breast wheel, undershot wheel, turbine wheel (what is the usual position of its axis?), Pelton wheel (undershot, made to stand water flowing under tremendous head), gearing, machinery, etc., in cyclopædia and works of reference.

QUESTIONS.

NOTE.—Take no account of friction in solving problems, but work by the "Law of Equilibrium."

1. A lever is 8 m. long and *f* is 2 m. from the weight end. F = 10 kg. What is W?

2. Radius of wheel, 10 dcm., of axle, 4 dcm., F = 25. W?

3. A boy can lift 80 lbs.; can he alone put a barrel weighing 0 lbs. into a cart 4 ft. high? How?

4. Lever acting on screw = 6 ft., distance between threads of ew (parallel to axis), ½ in., F = 60 lbs. W?

5. In the "endless screw" with connecting wheel and axle (Fig. 107), what is W, if [illegible] is the circumference described by the crank AB?

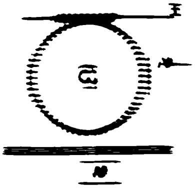


Fig. 107.

6. AB = 25 cm., cogs = 40, circumference of axle (a) = 10 cm., F = 20 kg. W?

7. Mention ten instances in which friction is very useful or even indispensable.

8. In the 4th question, *practically* would your pressure (W) be greater or less than what you obtain theoretically?

9. Does a machine *do* work?

10. Why do the men working "jack screws" to raise buildings, pull upon the lever by a series of jerks instead of with constant pressure?

11. Describe practical examples of levers of 1st, 2d, and 3d class that you have seen.

12. Arrange a set of pulleys (section) so that F = 5 lb., W = 25 lb.; so F = 7, W = 42.

13. Why do you pound against a drawer that "sticks"?

14. A boy *lowers* a heavy weight by means of a rope passing over a beam. Does the friction "favor" the boy? How is it if he raises the weight?

CHAPTER XII.

HEAT.

NOTE. — Heat is a name applied both to a cause (molecular motion) and to an effect (sensation). The physicist uses the term usually in the former sense. According to the **Kinetic Theory** the molecules of all matter are in irregular motion (like a swarm of flies). When this motion is increased in a body it is warmed; when this motion is decreased in a body it is cooled. **Heat** is therefore **a form of energy.** As we know from countless observations that this energy in a body is constantly being expended, energy in the form of heat is kinetic energy.

SOURCES OF HEAT.

EXP. 130. — With a small hammer strike obliquely the surface of a rock (flint, iron pyrites, etc.) while curtains of room are drawn. You "strike fire." What is the cause of the heat? (*b*) Pound a piece of coarse copper wire, or a nail, upon an anvil. Is the nail warmed? Why? (*c*) Place a gimlet bit in the bit stock, and bore rapidly into hard wood. Why is the bit hot? These results illustrate the *transformation* of mechanical energy into heat energy.

EXP. 131. — Take the temperature of the water which half fills a large test tube. Pulverize a teaspoonful of quicklime, and pour into the water. Reinsert the thermometer. Does the mercury rise slightly or fall? Part of the quicklime has united chemically with the water, producing heat. What do you do when you "build a fire"? You furnish conditions for what?

EXP. 132. — Pass a current of electricity through a very fine, short piece of platinum wire; or fasten a file to the positive pole of the source of the current, and rub it with the negative pole. [It isn't necessary that a battery in which there is chemical action shall be the source of a current of electricity.]

one in each hand, and immerse *horizontally* to equal depth in flame (of Bunsen's burner). Drop one, only when too hot to hold. Which do you drop? Why this instead of the other?

The distribution or passage of heat from molecules to other molecules that are adjacent is called **Conduction.** Metals are good conductors and glass is a poor conductor of heat energy. Do you know of any other poor conductors? If air were a good conductor what would happen to the end of the thin walled glass tube which you held horizontally?

Exp. 135.—**Fill a narrow test tube full of cold water, and holding by the bottom, heat the top in Bunsen's flame; when the top is boiling hot what is the condition of the bottom?**

Water is a poor conductor of heat and so are liquids in general, and gases. Do you know of any liquid that is a good conductor?

Exp. 136.—**Heat a test tube full of water into which walnut saw-dust has been put, holding tube obliquely over flame *F*, Fig. 108. Observe motion of saw-dust.**

(*b*) Cut a disk about 8 centimeters in diameter from light cardboard. Make of it a "wind mill" by cutting with scissors from circumference nearly to the center, and turning up edges to a little less than 45°. Stick pin upward through center and hold above flame.

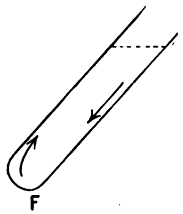


Fig. 108.

Masses of liquids (except metals, which are good conductors) and gases, must be heated by **convection,** that is, by *circulation.*

Heat expands fluids (see Exp. 146) and the colder and therefore heavier (per cubic centimeter) fluid upon the side falls and pushes the lighter, warm fluid, water or air upward. The cold fluid does not flow in "*to take the place of*" the warm fluid, but the warm fluid is pushed out and *gives place* to the heavier cold fluid.

marked. Plunge bulb of flask into hot water. What first happens to surface in tube? Why? What next happens? Why?

Exp. 140. — Arrange a flask as shown in Fig. 111. Place hand on bulb, what happens in beaker below? Why? Use the heat of both hands for awhile and then remove them. What happens as the bulb cools? This apparatus is called an "*air thermometer.*"

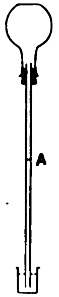


Fig. 111.

In general **Heat expands** solids, liquids, and gases. By this effect the intensity of heat is measured. **Temperature** refers to the intensity of heat. If the intensity is great, we speak of the body as being at a *high* temperature. Instruments for measuring temperatures are called *thermometers* if the temperatures are moderate, and *pyrometers* (usually platinum rods) if temperatures are high. Thermometers containing alcohol as the expanding liquid, are used to indicate very low temperatures, as those of the polar regions. Why? [See Section IV., Appendix.]

Exp. 141.— Examine carefully a chemical thermometer with centigrade graduations on one side and Fahrenheit on the other. Imagine that you have two thermometers precisely similar in every respect except in graduation and standing side by side as shown in Fig. 112.

The lower horizontal line represents the freezing points, and the upper the boiling points of the thermometers. Consider these in transferring the registration, as precisely like two ladders, *ten* of the spaces between the "rounds" of *C* being equal to *eighteen* of the spaces between the rounds of *F*. *Work with reference to the freezing point, but record with reference to zero* as in the following examples:

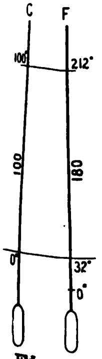


Fig. 112.

1. 15° C = what registration F?
2. 14° F = what registration C?

SOLUTION 1.

15 spaces above freezing point C = 27 spaces above freezing point F (that is, 10 C = 18 F, then 15 C = 1½ times 18 F), but 27 spaces above freezing point must be recorded with reference to zero.

32° + 27° = 59° F. *Ans.*

SOLUTION 2.

14° F means 18° below freezing point; but 18 spaces F = 10 spaces, C, therefore the mercury stands at 10° below freezing point C, but this must be recorded with reference to zero.

− 10° C. *Ans.*

A *maximum* (self-registering) thermometer may be made by putting a short piece of steel wire above the mercury and inclining thermometer, so that when the mercury falls. the adhesion between the steel and the glass will hold the wire at the highest point reached. A *minimum* thermometer is made by placing a short piece of glass rod in similarly inclined thermometer, containing alcohol instead of mercury. The glass rod below surface is drawn backward by the alcohol not breaking the surface film, and on reaching the lowest point remains there while the alcohol in rising flows above it.

The **Coefficient of Linear Expansion** of a body is the fraction of its length which a body expands when its temperature is raised from 0° to 1°. As you will see from Section VIII., Appendix, the expansion of brass is to that of iron approximately as 9 : 6. Advantage of this unequal expansion of the two substances is taken in making the **Compensation Pendulum.** In this, by proper adjustment, the upward expansion of brass rods lifts the bob and balances the downward expansion of longer iron rods. The center of oscillation is thus kept at the same distance below the point of suspension, regardless of the temperature. Mercurial compensation pendulums are also used.

The **Coefficient of Cubical Expansion** is the fraction of its volume which a body expands from 0° to 1°. For gases this coefficient is $\frac{1}{273}$, that is, 273 liters of a gas at 0° if heated 1° expand to 274 liters, and if cooled 1° contract to 272 liters. By the use of Mariotte's Law and this coefficient we are able to correct for varying temperature and barometric pressure, when we wish to make very accurate experiments with gases.

P. 142. — Fill three basins with ice water, blood warm water, not water respectively. Place one hand in the first and the hand in the last, and, after a little time, remove and place both s in the other dish.

; is a well-known fact that we can not rely upon the **sation** of heat in estimating with accuracy intensity ıeat. If our bodies could be kept perfectly normal, sation would be an approximately good standard.

For intensity affected by *distance* from source, see nt.]

QUANTITY.

NOTE. — A cupfull of boiling hot water does not contain so much it as a barrelfull of blood warm water. This may easily be ved by applying heat to these two quantities respectively of ice-d water.

A **Thermal Unit**[1] is the amount of heat necessary raise one kilogram of water 1°. This is approxi-ately the same anywhere upon the scale from 0° to)0°. A thermal unit is often called a *Calorie.*

EXP. 143. — In a large glass dish wrapped with flannel ("jacket") ıst removed from a warm wooden box whose inside temperature is bout 35°, mix as quickly as possible 1 kilogram of water at 15° and ; kilograms at 60°. Stir promptly with thermometer through hole in enter of non-conducting cover, and observe temperature. How ıear the theoretical result do you come? [Hot water may be simply oured into the cooler without the use of the extra dish.]

EXAMPLE.

1 kg. water at 15° = 15 Thermal Units { Introduced since water was at 0°. }
.5 kg. water at 60° = 30 Thermal Units
1.5 kg.) 45 T. U.
30° *Ans.*

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[1] Used in this book

Problem. — If I mix 10 kilograms water at 60°, 80 kilograms at 40°, and 120 kilograms at 80°, and *lose no heat by radiation, etc.*, what will be the temperature of the mixture ?

LATENT HEAT.

Exp. 144. — Take small pieces of ice and an amount of water as nearly of the same weight as you can. Place the ice in one dish and the water in a similar dish (Fig. 113). Apply heat by two flames *H* and *H'* of equal heating power if possible. Stir with glass rod the ice. When the ice is almost but not quite melted take the temperature of each. — If we could avoid unequal losses by radiation and in other ways perfect the experiment, using dry ice at 0° and water at 0°, what is represented in Fig. 113 would occur. While the ice was melting the water would rise to 80°. After this each would rise equally.

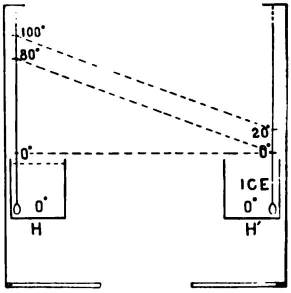

Fig. 113.

The **Latent Heat** of water is **80.**[1] By this we mean that it takes 80 times as much heat to melt a given quantity of ice as it does to raise the same weight of water 1°. It takes 80 thermal units to melt **1** kilogram of ice. We may repeat again by saying that it takes as much heat to melt 1 kilogram of ice as it does to raise 1 kilogram of water 80°.

Ice in melting absorbs heat. We put heat into ice at 0°, but instead of raising its temperature the heat does *mechanical* work upon the ice analogous to pulverizing, that is, it liquifies the ice. To melt ice work must be done against the force of cohesion. Thus energy is stored up in the melted ice as it is stored up in the lifted weight upon which mechanical work has been done (**Exp.** 83, *c*). Latent heat is not then really heat, but stored up energy. Melting

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[1] 79.9 +

“cooling process.” Eighty thermal units from some source intensely hot than the melting ice must come to the ice in s of that given out by the ice whenever 1 kilogram of ice is ed. Freezing is a “warming process.” In freezing 1 kilogram e water must give out 80 thermal units to objects more intensely han ice in excess of that which it receives. Vegetables do not e at 0°, but at, say, 2° below 0°. Even ice water in a cellar often prevent vegetables from freezing, because every kilogram e water in freezing must give out to objects colder than it 80 s of heat. This prevents vegetables from falling to their freez- point.

XAMPLE. — If I mix 40 kilograms of water at 90°, 60 kilograms 0°, and 10 kilograms of ice, if no heat is lost what will be the perature of the mixture?

40 kg. at 90° = 3600 T. U.

60 kg. at 80° = 4800 T. U.

10 kg. ice = – 800 T. U. (lost in melting ice)

110 kg.) 7600

69 – .1 + .

Exp. 145. — Find the Melting Point (i.e., Freezing or Solidifying int) of tallow by partly melting a quantity, and removing source heat, stirring a short time with thermometer, being sure that ne solidifies upon the bulb till after you have taken the temperature.

Different solids melt at different temperatures. With nstant pressure the Melting Point for any substance constant, and is the same as the Freezing or the lidifying Point. The latent heat of fusion is differ- t for different substances. Some substances decom- se into other chemical compounds instead of melting hen heat is applied. [App., Sect. IV. and VII.]

Exp. 146. — Mix pulverized salt and ice in alternate layers in a ick glass dish standing upon a wet piece of board. Place in the ixture a thermometer and a small covered beaker with a little ater in it. Be careful that no salt gets into the beaker. The tem-

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[1] Presumed to be at 0° unless otherwise mentioned.

perature observed should be at least below — 10°. Observe also water in beaker and the *outside* of the glass dish. In about ten minutes lift the dish with *attached* board.

The Freezing Point (and therefore the Melting Point when both salt and ice are melted together) of a saturated solution of common salt is far below 0°. In freezing the salt separates and the ice is nearly free from it. In order that salt and ice may melt together, they must absorb (make latent) a large quantity of heat from objects near by, and therefore these objects are reduced to a temperature below 0°. Substances whose Freezing Points are about 0° are easily frozen by such a **Freezing Mixture.**

There are many exceptions to the general law that "heat expands and cold contracts." Liquids that crystallize in solidifying, expand as they assume the solid state. Water expands in cooling from about 4° to 0°, and then there is a sudden and great expansion. When ice melts it contracts. The melting point of substances which contract in melting is lowered by pressure. [See Latent Heat of Steam, Exp. 152.]

SPECIFIC HEAT.

Exp. 147. — Take two large thin test tubes, and put into one a little mercury and into the other an equal weight of water (13.5 + volumes). Expose each equally for a little time in a small flame and rapidly take temperature of each, taking that of mercury first. Could we surround equal weights of water and mercury with perfect conditions on applying equal heat at *H* and *H'*, we should observe what is represented in Fig. 114. The mercury would rise 30° while the water was rising 1°. (See Appendix, Section V.)

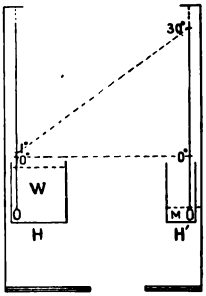

Fig. 114.

The **Specific Heat** of mercury is $\frac{1}{30}$. By this we mean that it takes only $\frac{1}{30}$ as much heat to raise a given weight of mercury 1° as it does to raise the same weight of water 1°. It takes only $\frac{1}{30}$ of a thermal unit to raise 1 kilogram of mercury 1°. Again we ay say that 1 thermal unit will raise 1 kilogram of ercury 30°. [Specific heat increases very slightly ith temperature, but this book will treat it as con-tant.]

The specific heat of ice is almost exactly .5. If we hould expose 1 kilogram of ice in the polar regions to an atmosphere of — 40°, of course the ice would soon acquire this temperature. It would then require 20 thermal units to raise the temperature of *this* ice to 0° again. Why?

EXAMPLE. — If I mix 80 kilogram of water at 40°, 4 kilograms at 90°, 100 at 80°, and 20 kilograms of ice at — 30°, what would be the temperature of the mixture, not allowing for losses of heat?

80 kg.	at	40° =	3200 T. U.
4 kg.	at	90° =	360 T. U.
100 kg.	at	80° =	8000 T. U.
20 kg. ice	at	— 30° =	— 300 raising to 0° — 1600 lost in melting
204 kg.			) 9660 T. U.
			47° + *Ans.*

The great latent heat and specific heat of water moderates the "extremes of climate." If the latent heat of water could be changed to 1, the extent of the disaster could be scarcely imagined. River valleys would be uninhabitable because of floods, and the rapid freezing and thawing would make spring in the temperate zones unendurable. If the specific heat of water were changed to $\frac{1}{30}$ like that of mercury, water would have far less effect in moderating temperature. Heat used in raising temperature is called *Sensible* Heat, in distinction from that used in overcoming cohesion. The latter becomes latent or changed to potential *molecular* energy. The varying specific heats of the metals (Appendix, Section V.). make unreliable the conclusions of amateurs upon the relative *conducting powers.*

ABSORPTION AND REFLECTION.

(OF RADIANT ENERGY ABSORBED AS HEAT.)

EXP. 148.—Take a bright sheet of tin or polished brass and reflect the radiant energy as you would reflect a ball, screening the object (hand or thermometer) upon which it is reflected from the direct radiation by any convenient screen.

(*b*) Blacken in the flame of a candle one tin can, and polish bright another. Put a thermometer into each, fill with cold water and set near any radiating surface, or expose to the direct heat of the sun. In which thermometer does the mercury rise faster.

Polished brass is one of the best reflectors, and lampblack is one of the best absorbers of the radiant energy absorbed as heat. Good absorbers are good radiators, and of course, bad reflectors. Good reflectors are poor radiators, and of course, poor absorbers. A substance can not be both a good absorber and a good reflector at the same time. Any ordinary object (one not developing heat within itself as flame) that is neither rising nor falling in temperature must be absorbing and radiating the same amount of heat energy. The apparent radiation of cold, when for instance, ice is brought near the bulb of a thermometer, is explained by this fact. When the ice is near, the thermometer is radiating more heat than it is receiving. Cold is merely absence of heat in a greater or less degree according to the "intensity of the cold." [For refraction and transmission of radiant energy see light.]

VAPORIZATION AND CONDENSATION.

NOTE.—If vaporization takes place slowly and quietly it is called *evaporation*, if rapidly and noisily, the vapor escaping from the surface of the liquid it is called *ebullition*, or *boiling*.

Exp. 149. — Put a flask half full of cold, distilled water upon a d bath, and heat. Dip into the flask a very slender, lighted er, reaching the flame down nearly to the water, while the water yet only warm. Remove taper quickly not getting smoke into the sk. After the water begins to boil adjust heat so that water will il quietly. Try taper again. Meaning of the different result? oes the air touch the surface of boiling water? Why not? What ushes the air off?

(b) Place a thermometer in the liquid, the bulb just below the surface, but not touching the bottom of the flask. At about what point does it stand? Raise the bulb just above the surface; how does the mercury stand? Double the heat of the flame, and test temperature of steam and water. Is there any perceptible difference in temperature with increase of heat? Do you observe any change at the mouth of the flask? Is the heat which "escapes the thermometer" doing any work?

Water[1] boils at **100° C.** The boiling point is constant. Additional heat only increases the rapidity of the vaporization without raising the temperature. The **tension** of the vapor of a liquid boiling in the open air is *one atmosphere.*

Exp. 150. — Put some fine salt into the water used in the last experiment (as much as will dissolve), and, boiling again quietly, take temperature of vapor and then of the boiling salt water.

(*b*) Put a small beaker one-third full of ether into a large beaker containing a little water. Place on *broad* sand bath, and as soon as ether begins to boil take its temperature. [Be careful that the ether does not take fire. If this accident happens, let ether burn up quietly. See that nothing combustible is near, especially above it.]

Different liquids have different boiling points. In general light liquids have a lower, and heavy liquids (including solutions of solids), have a higher boiling point than that of water. [App., Sect. VI.]

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[1] At sea-level, barometer at 760 mm.

Exp. 151. — **Franklin's Experiment.** In a well annealed, roun bottomed flask place a little water. Boil, raise from sand bat quickly and firmly stop with rubber cork, and invert in ring of reto stand. Pour on bulb a little cold water. Wipe dry and pour again. The bulb *V* contains hot vapor of water, which condensed by the cold water, relieving the liquid surfac of pressure; and the water will continue to boil thus ti the temperature is very much below the ordinary boilin point.

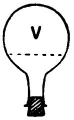


Fig. 115.

Water boils at a lower temperature upon mountain-peaks than in the valleys beneath, because the atmospheric pressure is less there. Vegetables must be cooked much longer at high altitudes. An ascent of about 290 meters lowers the boiling-point 1°. At Quito water boils at about 90°. Below the sea-level, as in the Dead Sea Valley, boiling water has a higher temperature than 100°. If water is inclosed, as in the boilers of steam engines, it may be heated far above 100°. If a boiler containing such highly heated water and steam explodes, much, if not all, of the water immediately turns into steam.

If, while water is boiling in them, two Franklin flasks be suddenly connected by bent glass tube just reaching through perforated corks the apparatus *inverted* becomes a "*pulse glass.*" The heat of the hand will expand the vapor, and drive the liquid into the opposite bulb. If a pulse glass contains as the liquid colored ether or alcohol, and the connecting tube be long enough to hold more than all the liquid, vapor only remaining in the bulbs, the apparatus becomes a **Differential Thermometer.** If the liquid stands higher in the right-hand arm of a differential thermometer, which bulb is in the warmer place?

Exp. 152. — Arrange apparatus as in Fig. 116, except do not connect chamber *B* with beaker *C* till water has been gently boiling in for some minutes. Let beaker be previously weighed, and water and beaker. Pass steam through r in C (which should be well "jacketed" covered, and the temperature taken just re passing in steam) till temperature is t 80°. Remove *B* and weigh *C*, finding much water condensed from steam has red the beaker. Water condensed from m has a temperature of 100°. Solve your blem and find out if this much water at 100° raise to 80° the amount at first in beaker. viously you got a lower temperature than that computed for the ture, why do you now get a higher one?

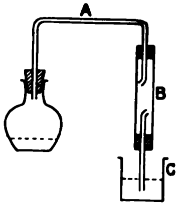


Fig. 116.

The **latent heat** of steam is **537** (about). This ans that it takes as much heat to vaporize a given ight of water *at 100°* as it does to raise 537 times as ch water 1° It means that it takes 537 thermal its to vaporize 1 kilogram of boiling water. It eans that 1 kilogram of steam at 100° in condensing to water at 100° gives out 537 thermal units.

EXAMPLE. — If I mix 10 kilograms of ice at — 40°, 20 kilograms water at 30°, 500 kilograms water at 20°, 10 kilograms at 0, and kilograms of steam at 100°. What will be the temperature of the ixture, *if no heat* is lost, and none received from without?

Weight.	Temperature.	Thermal Units.
10 kg. ice at	— 40° =	— 200 raising to 0° — 800 lost in melting
20 kg. water at	30° =	600
500 kg. water at	20° =	10000
10 kg. water at	0° =	0
10 kg. steam at	100° =	5370 10 kg. in condensing 1000 boiling hot water
550 kg.		)15970 T. U.
		29° + *Ans.*

Exp. 153. — From a flask containing *salt* water, and having an extra safety tube running through doubly perforated cork (like tube in Fig. 9), pass steam through the tube *ab* of apparatus (lamp chimney and tubes) shown in Fig. 117. Let water run from source (faucet) *S* as shown. It enters cold at *E* and emerges warm (why?) at *O*. Use only heat enough to boil water gently in flask. Taste water that drips into beaker from *b*.

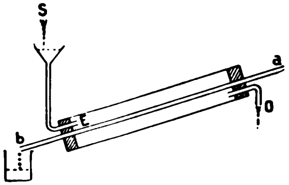


Fig. 117.

The apparatus shown is called a **Condenser,** and the *process* of thus separating a liquid from impurities is called **Distillation.** The flask is called a retort or still. The process of separating more or less completely liquids having different boiling points is called *Fractional Distillation.*

Exp. 154. — Heat a little water in the bottom of a deep beaker till it is quite warm. Lower into the beaker nearly to the water a *cold, dry* test tube. Moisture is deposited upon it.

Given equal volumes, a cold space can not hold as much vapor as a warm space. By the **dew point** we mean that temperature below which in cooling water-vapor can not be lowered without being deposited as dew. The deposit will begin in each case when the water-vapor exerts the maximum pressure which it can exert at that temperature. Though the air has nothing whatever to do in determining this temperature, the meteorologist says that when sufficiently cooled, *the air* deposits *dew.*

If we heat a cellar containing very damp air, the air *seems* to become more dry. It becomes capable of taking up more moisture, and therefore has the same drying effect upon damp substances, including the human skin, as though it had really become dryer and had remained at the old temperature.

That special science which treats of atmospheric phenomena, especially those resulting from heat and moisture, is called **meteorology.** When cold air comes in contact with warm *moist* air, ondensation produces *rain*. *Hail* is frozen rain. *Frost* is dew. If the condensation takes place slowly *mists* and *fogs* *Clouds* are only fogs at higher altitudes. If they form and an atmosphere at or below the freezing point *snow* is the If snow forms quietly in higher regions and falls in an phere below 0° the temperature of that atmosphere will be y raised to 0° by the "latent heat" given out in freezing. the expression "It's too cold to snow." In the same way contion into rain is often attended by a rapid rise in the temperaf the atmosphere due to the latent heat of the vapor given out ndensation. "Warm rains" are common. Why, then, does ll frequently cool the air of hot countries?

P. 155. — *To find the dew point* of the atmosphere in the room. to a bright tin dish put cold water and pieces of ice, stirring thermometer. Be careful not to breathe upon the outside of Take temperature when dew is *first* deposited. If moisture) is not deposited readily add a little salt with the ice. Wiping a bit with the finger will make deposit more evident.

P. 156. — Dip one hand in water and pass both hands back and rapidly through the air. Which hand feels cooler? (*b*) Dip bulb of the thermometer into ether at the temperature of the . Remove bulb and quickly blow it with small bellows. Observe ge of temperature. (*c*) Set water at the temperature of the n aside in two vessels, a tin dish and a porous cup, and in a half r take the temperature of each.

ubstances in vaporizing **absorb heat,** or, in unscienc language, "*evaporation cools*." Vaporization takes ce more rapidly in the open air, if

(1) The heat applied is greater.
(2) The surface exposed is greater.
(3) The temperature of the air is farther above its dew point.
(4) The air is in motion.
(5) The atmospheric pressure is less (barometer low). [Why?]

Exp. 157. — Arrange two thermometers (of like registration, or whose difference in registration you have observed) as shown in Fig. 118. A hollow wet wick passes from one into a dish of water. Why does the wet bulb thermometer stand lower than the dry bulb thermometer?

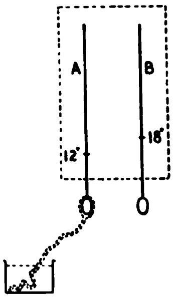


Fig. 118.

The apparatus is a **Psychrometer**, by which the humidity of the air *relative to the dew point* is indicated. If the air is nearly saturated the two thermometers stand nearly alike. If the air is at a temperature far above its dew point (relative to dew point very dry), the difference in the indication of the two thermometers is very great. By means of an empirical chart the dew point is quickly found when we know the differential reading of the psychrometer standing *protected from the wind.*

Exp. 158. — Place the bulb of a maximum thermometer under the tongue (or ordinary thermometer with another to observe temperature). What temperature is indicated?

The normal temperature of the interior of the human body is about 37° (98° F.). If the temperature is reduced much below this, or raised much above this, death is the result. The temperature is kept from going dangerously below the normal by chemical action within the body. It is kept from rising dangerously above the normal by evaporation (heat absorbed by) going on upon the surface of the skin. **Sunstroke** is simply an overheating of the interior of the body. Upon the borders of the Mohave Desert men sufficiently supplied with water can work in an atmosphere whose temperature is 46° (about 115° F.), because the air is so "*dry*" that evaporation keeps them from becoming overheated. In the damp atmosphere of Atlantic coast cities a temperature of 37° (98° F.) produces "sunstrokes" by the score.

THE STEAM ENGINE.

**. 159. — Fasten a screw into the bottom of a rubber stopple.
ɔple and place it lightly into mouth of stout flask in which
s gently boiling. Why does it rise and fall ?**

**. 160. — Examine a steam boiler and engine as to the follow-
ails: (1) boiler tubes; why are they used? (2) Safety valve; a
f what class, considering tension of steam
ce ? Considering tension of steam the
nce ? (3) Steam gauge (bent tube carry-
licator on inner end of coil and tending
ighten under pressure of steam, as rubber
oes under water pressure). (4) Water-
ınd gauge cocks. (5) Governor (Fig.
} from boiler, *S′* to steam chest, and *A*
:ted to shaft. (6) Steam Chest and
ler (Fig. 120), and (7) Shaft connec-
Fly-wheel, etc.**

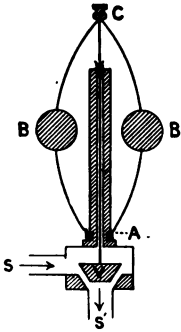


Fig. 119.

lefinite amount of heat can do a
te amount of work. Dr. Joule
vered by elaborate experiments
one thermal unit can do 424 kilogram-meters of
This is called the *Mechanical Equivalent of Heat.*

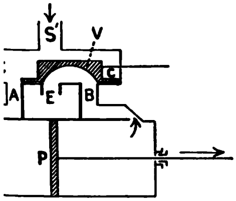


Fig. 120.

The **Steam Engine** is a machine for *transforming* the energy stored in steam into mechanical motion. By means of a sliding valve *V* moving in "steam chest" *C C*, the steam is alternately admitted through the "ports"
ıd *B* to the "cylinder" in which the piston *P*
s. The piston rod turns the "shaft," and the
ıg valve rod ("excentric rod") is moved by an "ex-
ic" fastened to shaft. You will notice that this

does not always move *in the same direction* as the piston rod is moving. After the steam is used it passes out alternately through the ports B and A, and through the "exhaust pipe" E. If E opens into the air the engine is *non-condensing* (or high pressure). If E opens into a closed chamber to be condensed by cold water jets, the engine is a *condensing* engine (or low pressure). Those two points in the circle of the shaft's rotation where the piston's force is exerted with no effect are called "dead points."

Investigations upon the subject of heat contributed largely to establish the modern doctrine of the **Conservation of Energy**; that is, the "sum total" of the energy or energies in the universe is constant. It is now known that energy is as *indestructible* as matter.

QUESTIONS.

1. Define convection, radiation, thermal unit, "steam jacket," latent heat, specific heat, dew point, tension of steam.

2. Transpose to the other scale 9°, − 10°, − 40° C, and 30°, 60°, 12 and − 6° F.

3. If the coefficient of cubical expansion were the same for glass and mercury, how would the ordinary mercurial thermometer work?

4. Why is there a space left between the ends of the rails on a railroad track? Mention other cases which you have observed in which "heat expands solids."

5. If 1680 cu. m. of coal gas at 0° in holder is warmed by the sun's heat to 15°, what will be its volume, if pressure remains the same? (*b*) If pressure is double?

6. If we mix without loss of heat 5 kg. of ice at − 20°, 20 of water at 80°, 60 of water at 40°, and 2 kg. steam at 100°, what is the temperature of mixture?

7. How many thermal units will be required to raise 1 kg. of ice to 40°? [Will it be *ice* then?]

8. How much heat will be required to vaporize 1 kg. of water, whose temperature is 80°?

9. "Ice is no colder than the water in which it floats," why then should it be excluded from the kettle, if we are in a hurry to boil the water?

10. Why haven't you the melting point of black walnut given in any of the tables?

11. How much ice in closed chamber would be melted by 1 kg. of water at 100°?

12. If 1 kg. of an alloy at 100°, put into the same chamber, melts only 50 gm. of ice, what is the specific heat of the alloy?

13. Water will boil quicker in a tea-kettle with bright or smutty bottom? Why?

14. In a cool room, which *feels* colder, marble or woolen, both being at the same temperature? How would it be in the sunshine of the hot desert? Why in each case?

15. Why do both stokers and Arctic explorers wear woolen? [Its non-conducting qualities are partly due to the non-conducting air confined within it.]

16. What apparatus might you use to cook potatoes on a high mountain as quickly as in the valleys? What are the "vacuum pans" of the sugar refineries?

17. Water distilled from solid impurities *rapidly* or *slowly*, will be purer? Why?

18. We have more dew on still, or on windy nights? On cloudy or on clear nights? Under the tree or in the open field? We have more frost deposited upon wooden or upon stone sidewalks? Why?

19. A teamster upon a hot, moist day is in more danger of sunstroke, when the difference in reading between the thermometers of psychrometer is great or little?

20. Enumerate a large number of "losses of energy" cutting down the *efficiency* of the locomotive.

21. Why are icebergs often enveloped in fog?

22. Why will hot water "break glass"? Why will heating the neck of a bottle often loosen the stopple?

23. What causes the winds? (*b*) Does the earth's rotation affect their direction?

24. Rough or polished surfaces will cause a substance to become heated more rapidly?

25. Snow melts more rapidly under a tree than in the open field. Why?

26. On the top of a high mountain one's face is blistered in the sun more quickly than in valley. Why? Why are the mountain peaks so cold then?

27. Lead after beginning to melt, melts more rapidly than ice. Why? [Appendix, Sections VII. and IX.]

28. Why does the mercury *at first* fall, when a cold thermometer is plunged into hot water?

29. Ask and answer some good question which you found in some other book? One of your own originating?

30. Give some experiments or illustrations which could easily be added to the list in this chapter.

31. How would it affect the climate, if the latent heat of steam were changed from 537 to 1? (*b*) How would it affect the steam engine?

CHAPTER XIII.

STATIC ELECTRICITY.

NOTE. — All apparatus must be kept warm and *dry*, and as far as possible free from dust. Do not bring apparatus from a cooler to a warmer room just before using it. Why? Many of the experiments given in "the books" cannot be performed satisfactorily in damp climates except upon unusually "dry" days.

EXP. 161. — Rub a piece of amber upon silk, spread out upon the table, and bring it near bits of dry paper.

The word electricity is from the Greek word "elektron" meaning amber. This experiment was performed more than 2,400 years ago. Electricity "produced" by friction is called for convenience Frictional or **Static Electricity,** though the student will hereafter find out that there is but *one* electricity.

It should be remembered that we do not really *produce* electricity any more than we produce weight when we raise the clock weights. In this case we simply furnish the conditions under which weight may do work. When we press the empty beaker down into the water (Fig. 13), we do not produce buoyancy; but we furnish the conditions under which buoyancy acts, or is capable of doing work. When we by winding coil up the watch spring, we do not produce elasticity as a property of matter, but we furnish the conditions under which elasticity may do work. By the convenient expressions "producing electricity" and "generating electricity" we mean furnishing the conditions under which electricity may do work. The electrified amber possesses potential energy, due to previous work done upon it. This energy becomes kinetic while it is doing the work of drawing the bits of paper to itself.

[illegible] of a warm glass [illegible] glass [illegible] near the [illegible] the [illegible] portion of the [illegible]

[illegible] flannel, and [illegible] Afterwards [illegible]

[illegible] of [illegible] to prevent [illegible] and [illegible] The [illegible] rubbed sealing wax [illegible] and [illegible] glass [illegible] with silk. [illegible] near suspended [illegible] attracted [illegible] the glass with silk [illegible] with [illegible] and [illegible]

[illegible] are said to [illegible]

Bodies with like charges repel each other, and bodies with unlike charges attract each other. If we have given two bodies oppositely charged, whose kind of charge is respectively known, to find whether a third body is charged, and if so, with what kind of charge, *repulsion is a much better test than attraction.* Why?

The attractions and repulsions between bodies due to electrification are *mutual.* One does not attract the other any more than the other attracts "the one." In general, any one of the following substances becomes positively electrified when rubbed with any one below it in the list, and negatively electrified when rubbed with any one above it :

1. Fur.
2. Flannel.
3. Glass.
4. Cotton.
5. Silk.
6. Metals.
7. Sealing wax.
8. Resin.
9. Sulphur.
10. Gutta Percha.

Exp. 162. — Suspend by means of parallel silk threads two pith balls having smooth surfaces so that they just touch each other. Threads may fall from a cork with or without handle as in Fig. 123. Touch the balls with an electrified body.

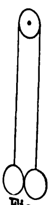


Fig. 123.

(*b*) To the lower end of a brass rod or wire having on top a knob of similar material, and passing through a cork, fasten two strips of gold leaf (or of aluminum foil). The rod may be flattened slightly to bring the "leaves" closer together. They *must touch* the rod, though they may be fastened with wax. Place the whole in a glass bottle as in Fig. 124. Touch the knob with a small electrified body, and observe the action of the leaves. Do the leaves remain separated for a while before collapsing?

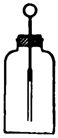


Fig. 124.

An **electroscope** is an instrument for readily detecting by the action of repulsion between its indicators, the presence of a charged body. By it we may also determine whether the charge is positive or negative. The most common forms are the gold-leaf and the pith-ball electroscopes. If a single pith ball hangs by a rigid thread to a brass rod carrying a graduated quadrant, as the deflection can be readily measured for the purpose of comparing the intensity of charges, the apparatus is a simple *electrometer.*

Exp. 163. — Bring a positively and strongly charged body near, without touching, the knob of a gold-leaf electroscope. No spark should pass between the body and the knob. The leaves slowly diverge. Remove the body, and the leaves immediately collapse. This shows that the leaves were charged only during the presence of the electrified body.

(*b*) Repeat, but touch knob of the electroscope, and remove finger before the positively charged body is removed. The leaves do not immediately collapse when the electrified body is removed. Touch knob with strongly and negatively electrified sealing wax. The leaves diverge further, showing that the electroscope was charged negatively by means of a positively charged body.

A body charged by the *presence* of an electrified body without contact with it is said to be charged by **induction.**

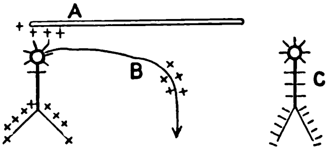


Fig. 125.

The last experiment shows how to charge a body by induction. Fig. 125 gives a theoretical explanation of the process, which explanation may be helpful in remembering the facts. The positive charge on the glass rod *A* attracts from the neutral electroscope a negative charge to the knob, and repels a positive charge to the leaves. As long as the positively charged rod is near the knob, the negative charge in the knob is said to be *bound*, and the positive charge in the leaves is repelled. When the knob is touched, the positive charge "escapes" to the earth through the experimenter's body as shown by the line *B*. After the finger and then the rod are removed, the negative charge in the knob, being no longer *bound* by the presence of the positive rod, becomes *free*, and distributes itself over the whole body as represented at *C.* If the rod is removed without first connecting the electroscope to the earth, the positive charge of the leaves and the negative charge of the knob attract and neutral-

ize each other, causing the leaves to collapse. Although there is only one electricity, many authors speak of "positive electricity" and "negative electricity," meaning respectively a positive charge and a negative charge.

Exp. 164. — Fasten a test tube mouth downward with wax to the inside of the cover of a tin pail *A*, (Fig. 126). Solder a brass nail to the inside and center of a larger cover, after the point of the nail has been cut off so that it has the height of the edge of the cover. Fill this cover *B* with melted wax, leaving the nail flush with the level surface of the wax. Connect lower tin to the earth through gas pipe. Electrify solidified wax with fur or flannel, and place cover *A* upon it. Raise *A* and touch with it the knob of a positively charged electroscope. *A* is positively charged by electricity drawn from the earth through the central nail by induction from the negative wax. Replace *A* and removing again, touch it with the finger. The charge is felt as a slight "shock." This may be repeated many times without again electrifying the sealing wax.

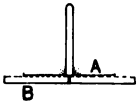


Fig. 126.

An **electrophorus** is an apparatus for the production of electrification by **induction.**

Exp. 165. — Turn the plate of a small Toepler-Holtz or Wimshurst machine till the crackling sound indicates that its separated terminals or poles are moderately charged. By means of a small **proof-plane** determine which pole is positive. This is done by charging an electroscope positively, and carrying a charge with the proof-plane from the pole to the knob of the electroscope. If the leaves diverge further the pole is positive, if they collapse and then diverge the pole is negative. [A proof-plane may be made by waxing an inverted test tube to the center of a tin cover. This should always be used in testing a highly charged body, otherwise the leaves of the electroscope are torn by the violence of the repulsion.]

Toepler-Holtz and Wimshurst machines are complicated devices for "producing static electricity" by induction, very little friction being employed. These should work well even in damp weather. They are too complicated to be studied in detail by beginners.

[illegible] mass not carrying a graduated quadrant, is the deflection ca[illegible] electroscope, for the purpose of comparing the intensity [illegible] charges, the apparatus is a [illegible].

Exp. [illegible]. — Bring a positively and strongly charged body near without touching, the knob of a gold-leaf electroscope. No spark should pass between the body and the knob. The leaves slowly diverge. Remove the body, and the leaves immediately collapse. This shows that the leaves were charged only during the presence of the electrified body.

[illegible] Repeat, but touch knob of the electroscope, and remove finger before the positively charged body is removed. The leaves do not immediately collapse when the electrified body is removed. Touch knob with strongly and negatively electrified sealing wax. The leaves diverge further, showing that the electroscope was charged negatively by means of a positively charged body.

A body charged by the *presence* of an electrified body without contact with it is said to be charged by **induction.**

The last experiment shows how to charge a body by induction. Fig. 125 gives a theoretical explanation of the process, which explanation may be helpful in remembering the facts. The positive charge on the glass rod A attracts from the neutral electroscope a negative charge to the knob, and repels a positive charge to the leaves. As long as the positively charged rod is near the knob, the negative [illegible] knob is said to be bound, and the positive charge in [illegible] [illegible]ed. When the knob is touched, the positive [illegible] to the earth through [illegible] [illegible] B. After the [illegible] [illegible] charge in the [illegible] [illegible] of the positive [illegible] whole body [illegible] connec[illegible] leav[illegible]

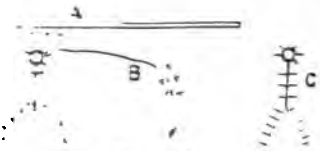


Fig. 125.

A positively charged body is said to have a higher *potential* than the earth whose average potential is taken as zero. A negatively charged body is said to have a lower potential than the earth. The flow of electricity is from a higher to a lower potential; metals, charcoal, acids, living vegetable and animal tissues, water, moist earth, etc., being good conductors. Resins, sulphur, gutta percha, glass, silk, porcelain, dry air, etc., are poor conductors. The latter are also called *insulators* or *dielectrics.* Though he may not at this point comprehend fully its meaning, it will be well for the student to remember that in studying Static Electricity he is studying electricity of *high potential.* This will be made clear in subsequent chapters.

Exp. 166. — Prepare a flat cake of sulphur about 2 centimeters thick. Suspend by a silk thread a ball electrified by contact with positive knob or pole of the machine. Place the knob of the gold-leaf electroscope a little more than 2 centimeters below, and quickly insert the unelectrified cake of sulphur. The leaves diverge more as though the ball had been brought nearer or had suddenly received a stronger charge.

Induction acts more readily through some dielectrics than through others. The specific inductive capacity or *dielectric constant* of sulphur is much greater than that of air.

Exp. 167. — Fasten a brass knob to a brass rod, and passing rod through cork, hang to rod a short brass chain. Place the cork in the mouth of a jar which is coated inside and outside with tinfoil as shown by dotted lines in Fig. 127. Charge the inside coat positively by a somewhat prolonged contact with the positive pole of the machine in action, while the hand, in contact at the bottom with the outside coat, holds the jar. The outside coat becomes negatively charged by induction through the glass, and *as a stronger positive charge is given to the inside coat a stronger negative charge is bound upon the outside coat.* Set the jar carefully (without breathing upon the apparatus) upon the table. Place one knob of a discharger (wire carrying two knobs and insulating handle *H*, Fig. 128), first against the outside coat, and bring the other knob promptly against the knob of the jar. A *disruptive* discharge takes place through the dielectric air before the two knobs touch each other. After a few minutes obtain another very weak discharge in a similar manner.

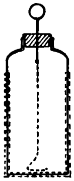


Fig. 127.

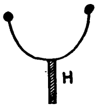


Fig. 128.

Condenser or "**Leyden Jar**" is composed of two conductors, separated by a dielectric or insulator. ıot at all necessary that the form be that of a jar. nside coat may be charged negatively, and the e positively. The "flow" or "current" is then he outside coat to the inside. The weak charge always left after the first discharge is called the *al* charge. A thunder cloud usually charged posi- the dielectric air, and that portion of the earth charged negatively by induction, form a huge n jar. One cloud may be charged positively, r negatively, and the discharge take place from st to the second through the air.

168. — Prepare a Leyden jar with movable coats by taking ıg glass dish (*a*, Fig. 129), and fitting a tin coat inside and soldering a large copper wire *b* carrying to the inside coat. Charge the jar. By ıf a glass rod remove inside coat, and then ıgers the glass, touching the glass to an ope. Bring the two conductors together. no spark. Place the whole together again lly as possible, and discharge jar with a er.

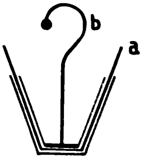


Fig. 129.

lielectric is by no means passive during the process of char- l discharging the conductors which it separates. Electricians ıved that while the conductors are charged the dielectric is rain. In the case of glass so situated, the glass affects light hrough it as though it were resisting great mechanical stress. tric in this state is said to be *polarized*. The polarization shown in the case of the dielectric turpentine by floating ort silk threads. Between pointed conductors oppositely the threads assume a position parallel to each other with s towards the conductors.

169. — Let a large number of pupils join hands in a curve. at the end hold the Leyden jar while it is being charged. as it is moderately charged let the pupil on the other end urve touch the knob.

The effect of the passage of a current of electricity of *high potential* through the living body is called a **shock.** If a battery of several jars were connected the shock might be dangerous to receive.

EXP. 170. — Separate properly the poles of the electrical machine. Rapidly turn the plate, and observe the path of the disruptive discharge. Observe odor about the machine.

The path of the discharge is straight only when it is very short. There are several reasons for this, the tendency to follow the line of least resistance in the dielectric being one. The discharge changes part of the oxygen of the air into ozone, which has a slightly sulphurous odor. (See Ozone in Chemistry.)

EXP. 171. — Hold a dry card between the poles of the electrical machine, and pass an electrical spark through it. In what way does the hole differ from that made by a pin?

EXP. 172. — Sharpen the end of a short piece of copper wire. Wind the wire about the positive knob of the machine with the sharpened end projecting towards the negative knob. How does the point affect the discharge? Darken the room, and observe glow about the point.

(*b*) Separate as far as possible the knobs, and turning the point aside a little, hold the back of the hand near it while the machine is in vigorous action. Observe wind and "cobweb" sensation. Hold also the flame of a candle having very small wick. The flame should be blown out by the rush of the molecules of air repelled from the point.

The last two experiments give meaning to the names "*disruptive discharge*" and "*convective discharge.*" The latter takes place from points. These favor the rapid and quiet discharge of electricity. Indeed, a body having pointed projections cannot retain a charge. St. Elmo's fire is but a convective discharge, of the variety ed "glow" discharge, which takes place from or rards the pointed mass of [illegible].

Exp. 173. — Hang two pith balls by silk threads so that one ches the outside and the other the inside of a tin can. Support e can on the positive pole of electrical machine and ectrify it. The ball on the outside is repelled, while at on the inside is unaffected.

Fig. 130.

Static electricity "resides" on the outside of a ollow conductor, so that a hollow conductor has the ame capacity or "will hold" as much electricity as a lid one of the same outside diameter. When the lectricity "flows," however, the solid conductor conducts better, e "current" not being confined to the surface.

Exp. 174. — Repetitional Experiments. Place a wig on a metallic ead and electrify. Why do the hairs stand on end? (b) Ignite as jet between the poles of the electrical machine. (c) Ignite ther placed in shoal glass or porcelain dish. (d) Mount on point f steel needle two crossed, sharpened wires fastened at center by ammering, and bent at the four sharpened ends like tubes of arker's mill. Connect needle with positive pole. The "Electric hirl" is the name of the apparatus. (e) Cut a large number of iamond-shaped pieces of tinfoil about one centimeter long. Fasten hem in a spiral upon the outside of a freshly varnished tube, so at they nearly but not quite touch. After apparatus is dry, connect and pass electric spark around this "luminous tube." (f) Hang to brass rod A, Fig. 131, two bells, B by brass chain, and C by silk thread, and between them hang brass clapper by silk thread, so that it lacks about one centimeter of touching each bell. Connect A with one pole and C with the other by chains. These "electric bells" ring as the machine is worked. (g) Support a square piece of dry plank upon four stout dry bottles. Upon this "insulating stool" let one pupil stand, and ld chain connected with positive pole. The pupil becomes charged sitively as machine is worked. The hair rises, and sparks may drawn from any portion of his body, stronger if the second

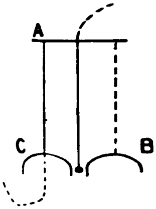


Fig. 131.

pupil holds a chain connected with the negative pole. (*h*) Sta brass rod with knob into bottle of water. Charge water holdi bottle in one hand. Touch knob with the other hand. This w the earliest form of the Leyden jar. (*i*) Connect a horizontal t cover with one pole, and a cover below with the opposite pol Electrifying, make light images of pith "dance" between the plate (*j*) Wind closely around a steel wire a fine insulated copper wir Pass small disruptive discharges or a steady "current" through th copper wire from one pole of the machine to the other. Has th steel wire assumed any new properties? Will it attract small piece of iron?

Exp. 175. — Connect a Geissler's tube (a glass tube containing rarefied air with platinum wire fused through the ends) to the poles of the electrical machine, and vigorously work the machine. A beautiful glow and play of colors appear, better observed if the room be darkened.

The **Aurora Borealis**, or Northern Lights, is believed to be caused by the currents of electricity passing through the rarefied air in which the play of colors is seen. If the air be still further exhausted in a Geissler tube, a point is reached beyond which the highly rarefied air becomes an insulator as before any exhaustion.

Lightning Rods oftener protect buildings by securing a rapid *convective* discharge from the cloud to the earth or *vice versa*, than by conducting a disruptive discharge. Among the requirements fo good protection are the following: —

1. The rods should be made of iron or copper with flat cros section or of separate wires. Each rod as far as possible should b without joints or with few and carefully made joints.
2. The rods should rise from all the higher portions of the build ing, as chimneys, etc. The top of the rod should be composed o several *pointed* projections made or covered with metal which resist oxidation.
3. Each rod should be separately carried into the *moist earth* and packed about with finely broken charcoal, or connected wit

arge metallic plate. Underground iron gas-pipe and water-pipe ar the rod should be connected with the grounded portion of e rod.

4. To prevent lateral discharges, all large metallic conductors, as n roofing, etc., should be connected with the nearest rods, and hould also be separately earthed.

It should be noted that we have sometimes in thunder storms what corresponds to the so-called "cloud-burst" among rains, or the "cyclone" among storms. Ordinary protection of a house against rainfall would avail little against a "cloud-burst," and ordinary precautions against heavy winds would avail little against a "condensed cyclone." Of two thunder clouds having each enormous surfaces, and having each *bound* charges, the charge of one may become suddenly *free* by the discharge of the other, and a terrific *rushing*, *oscillating*, and disruptive discharge from the one will take place to the earth. Rods which would afford ample protection in all ordinary thunder storms would afford little protection against such an impulsive rush discharge. Rods detached from the building would lessen the danger from such a discharge. Tall excurrent trees standing eight or ten meters from the building, by vicariously offering themselves to the stroke, would assist in protecting the house. [See Franklin, Faraday, Static Electricity, and Lightning in cyclopædia, and views of Lodge on "Lightning Rods" and Harris's system of protecting ships, in an electrical dictionary.]

NOTE. — The student must not overestimate the *comparative* importance of static electricity. Current electricity or voltaic electricity, soon to be studied, is of far more economic importance. High potential or static electricity is needed to produce mechanical disruptive effects, physiological "shocks," and direct heating effects in the dialectric without contact of conductors; but ordinary current electricity, that is electricity in the current state, produces directly or indirectly nearly all of the useful effects sought after by those who at present invest in electrical appliances.

QUESTIONS

1. How would you *in the simplest way* determine whether a body suspended by a silk thread was electrified or not?

2. How would you determine what kind of electrification it possessed?

3. How would you charge an electroscope positively by induction?

4. Why is a proof-plane used by electricians in charging by contact a gold-leaf electroscope?

5. Why should you not breathe upon the knob of a charged Leyden jar while holding it?

6. Given a charged thunder cloud above a house, would it be better that there should be a smoking fire of green wood in the open fireplace or that there should be no fires in the house? Why?

7. Given a charged cloud above and a fire of green wood upon a large bed of coals, would it do any good to pour water on and put the fire out?

8. When is a charge *bound* and when *free?*

9. Static electricity "resides" upon the outer surface of hollow or of solid conductors. Give *one reason* why the charge in a cloud becomes more intense as many minute drops condense into larger ones.

10. Why should lightning rods be pointed above? (*b*) Why should they reach *moist* earth below?

CHAPTER XIV.

MAGNETISM.

Exp. 176. — Obtain a piece of rock called magnetic iron oxide or destone, and dip it into iron filings. Do they adhere to one part y more than to other parts? Will the filings adhere to ordinary cks?

(*b*) Try to make the filings adhere to a common steel needle. ub *one* end of the needle with the iron oxide, using one of the two rtions of the rock to which the filings abundantly adhered, and bbing the needle from the center towards the end, carrying the ck back to the center of the needle through the air. Will any ngs now adhere to the rubbed end of the needle? Will any here to the end that was not rubbed? Roll the needle in filings. what portions of the needle do the filings most adhere?

(*c*) Will the rock now attract filings as well as before, or has it t part of its energy in giving energy to the needle, just as a mov- bat loses part of its energy in giving energy to the ball? Be eful about this investigation.

A **magnet** may be defined as a body having a special raction for common iron, and possessing two "poles" wards which the attraction is stronger than towards ual areas elsewhere upon the body. [See Exp. 180 r an apparent increase in the number of poles.] Mag- ts are called natural or artificial according as they e found "in nature" or are "made." The exper- ent shows one way of making *permanent* magnets. rmanent magnets are made out of steel, the two incipal forms being the *bar* magnet and the *horse- oe* magnet.

Exp. 177. — Float the piece of magnetic oxide on a flat piece of cork. Does it show any tendency "to point" in some definite direction?

(*b*) Cut a narrow groove in the cork to hold the needle, and pointing the needle westward float it. Does it remain pointing west? Point the needle east. Does it remain so pointing?

An ordinary **magnetic needle** is simply a magnet so mounted that it is free to turn in a horizontal plane. It may be mounted by (1) floating, (2) suspending by untwisted fiber, or (3) supporting upon a pivot. The end of the needle which tends to point northerly is called the *north-seeking* pole, and the opposite end the *south-seeking* pole. The north-seeking pole of permanent magnets is usually marked *N* or + and is often called the positive pole.

Exp. 178. — Pass a steel knitting needle through a flat piece of cork, and fit two pins into the cork at right angles to the needle and in the same plane. Adjust the needle so that it will remain horizontal when pointing nearly east and west, the pins being supported horizontally. Turn the needle so that it points nearly north and south, and magnetize by rubbing towards the north end with the south-seeking pole of a strong magnet and toward the south end with the north-seeking pole, carrying the pole back through the air and being careful not to move the needle with reference to the cork. Mount again upon pins and the north end *N*, Fig. 132, "dips" as though it had become heavier. [See Exp. 187 and comments.]

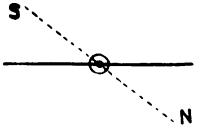


Fig. 132.

A **dipping needle** is a magnet mounted upon an axis running horizontally through its center of gravity, so that the needle is free to turn in a vertical plane. The amount of the dip is called the **inclination** of the needle, and is in general different for different latitudes, in northern latitudes the north-seeking end dipping, and in southern latitudes the south-seeking end dipping. What is approximately the inclination for your locality?

Exp. 179. — Bring the north-seeking pole of a strong bar magnet near the north-seeking pole of a magnetic needle. Is it attracted or repelled?

(b) Bring the north-seeking pole of the bar magnet near the south-seeking pole of the needle.

(c) Repeat (a) and (b), using the south-seeking pole of the bar magnet.

(d) Force the north-seeking pole of the needle up very near the north-seeking pole of the bar magnet. It is attracted. Pull it away at once, leaving it at some little distance away. It is again repelled.

(e) Hold a piece of *soft iron* near first one pole and then near the other pole of the needle. Is there repulsion in either case? [See soft iron, Section I., Appendix.]

Like poles repel and unlike poles attract each other. That portion of space about a magnet throughout which its influence perceptibly extends is called its **field.**

If a weak pole be forced near to a strong like-seeking pole, there is a temporary reversal of polarity in the weaker magnet, and the two apparently like-seeking poles attract. If the weak pole remains n contact or nearly in contact with its powerful neighbor, there is permanent reversal of polarity. The attraction between a magnet nd soft iron is *mutual.* The attractions and repulsions between magnets are mutual, but *repulsion is a far better test of polarity han attraction.* Why? In experiments requiring observations of he differing effects upon a magnet needle, the needle should be laced at some distance from all masses of iron not purposely involved in the experiments. Why?

Exp. 180.—Magnetize a knitting needle by rubbing its center with the north-seeking pole of a strong bar magnet, and its two ends outward with the south-seeking pole, repeating the operations several times. Roll the needle in iron filings, and note that there seem to be *three* poles in one magnet as shown in Fig. 133. Notice carefully whether the filings attached to the center all point in the same direction. We have really made *two* magnets out of one piece of steel, with two south-seeking poles at the center. Lay the needle upon a smooth surface, and bring south-seeking pole of the bar magnet near its center, and observe repulsion. Test also each end pole by repulsion. We may by properly rubbing produce poles as shown in Fig. 134.

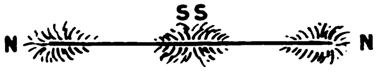


Fig. 133.

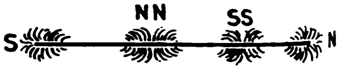


Fig. 134.

Consequent poles are double poles formed between the two terminal poles of a magnet by irregular magnetization. These, of course, are to be avoided as much as possible in all ordinary magnetization, as they tend to weaken materially the two normal poles. While a magnetized bar of steel, *considered as one magnet*, may have *more* than two poles, it can never have *less* than two poles. The double pole *SS* (Fig. 133) is called a consequent pole; that is, it is spoken of as *one* pole. Such a magnet is said to be anomalous. The line joining the two poles of a normal straight magnet is called the *magnetic axis*. This axis may not correspond with the longitudinal axis of the magnet, especially if the cross section of the magnet is large. For carefully made magnets, however, of small cross section, these two axes may be considered to coincide. Consequent poles may be avoided by rubbing with opposite poles from the center of the piece of steel as directed in Exp. 178, or by rubbing with *one* pole from one end to the other of the steel

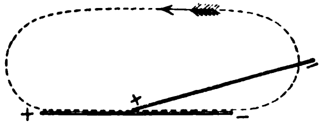


Fig. 135.

steadily carrying the pole back through the air. The end of the steel which the influencing or *inducing* pole leaves for its return through the air will become possessed of opposite polarity as shown in Fig. 135. The steel should be turned upon its longitudinal axis that all parts of its lateral surface may be rubbed.

Exp. 181. — Magnetize a small steel sewing needle and test its polarity. [It will be more convenient and prevent confusion, if in magnetizing sewing needles the pointed end is always made the north-seeking pole.] Break the needle into two pieces with pair of pincers, covering with cloth that the free piece may not "fly." Test each piece for polarity. Break one of the two pieces again and test. Each piece is a magnet.

(*b*) Fill a long half-inch test tube nearly full of *steel* filings. After it has been laid horizontally and tapped till the filings have a level surface, draw one pole of a bar magnet over the test tube. Do this several times, just as though magnetizing a piece of steel. Do the filings take, out of their previous confusion, any definite position with reference to each other and the tube? Regarding each end of each separate filing as a pole, could we properly describe what has happened by saying that the contents of the test tube had become "polarized"? Shake the test tube vigorously. What hap-ens? Polarize again the surface filings by applying the magnet.

(*c*) Dip the end of a magnetized knitting needle into *iron* filings. ote carefully the amount of filings which it will lift. Hammer the eedle vigorously upon an anvil for some little time, and test by lings as before. Is the magnet weaker or stronger than before?

(*d*) Test a short magnetic needle, noticing how many iron filings will pick up. Heat needle to redness, and keep at the red heat r several minutes. Cool by plunging into water, dry and test with ings. Is it now a stronger or eaker magnet than before?

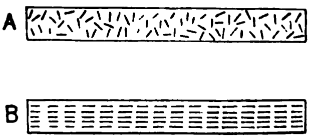


Fig. 136.

The **theory** respecting the in-rnal condition of magnetized n or steel is that the molecules e themselves magnets before the dy is magnetized, but these are ranged confusedly as shown in Fig. 136, so that there is no external manifestation of magnet-n, that is, no *free* magnetism. After magnetization of the body the molecules are supposed to be arranged with regularity as shown at *B*, the north-seeking poles pointing towards the north-seeking end of the body, and the south-seeking poles pointing towards the south-seeking end. The body is then said to be *polarized.* If all of the molecules are so arranged the body is said to be magnetized to *saturation.* This theory explains (1) why any portion broken from a permanent magnet is itself a magnet, (2) why pounding a strong magnet or letting it fall weakens it, (3) why heating to redness destroys the magnetism, as we know that heat increases the irregular molecular motion in bodies, (4) why rubbing with another magnet will make a magnet of steel, and why a powerful magnet may reverse the polarity of a weaker one, (5) why gently tapping while magnetization is being produced hastens the process, and (6) why there is a sound heard, analogous to the "tin cry," when powerful soft iron magnets are suddenly demagnetized and magnetized.

Exp. 182. — Place a piece of nickel (not the coin, which is only partly nickel), and a piece of bismuth upon the table, and see if they are each attracted by a magnet.

Iron is not the only metal attracted by a magnet. Nickel, cobalt, and some other substances, are attracted. Bismuth, antimony, and some other substances, are not only not attracted, but are repelled by either pole of *powerful* magnets. Substances attracted by magnets are said to be *magnetic* (or *paramagnetic*), and substances repelled are said to be *diamagnetic.*

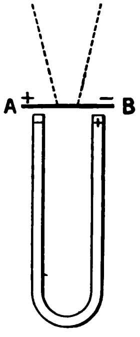


Fig. 137.

Exp. 183. — Suspend a piece of soft iron (*A*, *B*, Fig. 137) above a good horseshoe magnet. Test the polarity of the soft iron with a bar magnet. It will be found as shown in the cut. Remove the sof iron from the field, and test polarity first with ligh needle suspended by long delicate untwisted thread and again with heavy pivoted needle. With th first it shows slight polarity; with the secon none.

The influence exerted by a magnet to produce polarity in bodies within its field is called **induction** The soft iron is said to be made a magnet by induc tion. "Nothing but a magnet is attracted by a magnet," for the substance must be, or must be made, a magnet before attraction takes place. Soft iron is sensibly a magnet only while it is within a magnetic field, and a soft iron magnet is therefore called a *temporary* magnet. Steel, as we have seen, retains its magnetism after removal from the field, and a steel magnet is therefore called a *permanent* magnet. The slight traces of magnetism which a piece of soft iron retains after removal from a magnetic field is called *residual* magnetism. [See Exp. 201.]

Exp. 184. — Take three approximately similar pieces, one of soft iron, soft steel, and hard steel respectively. Stand the three vertically into iron filings, and with bar magnet touching in succession the top of each, raise quickly and detach from the magnet the piece without long contact. Gently rap with a lead pencil each piece as soon as it is removed from the magnet. Which lifts most filings? Which retains the larger per cent of what it has lifted?

Steel is magnetized and demagnetized less rapidly than a similar piece of soft iron in a field of equal strength. This power of resisting magnetization and demagnetization is called **coercive force.** Hard steel has great coercive force and soft iron very little. [See Electro-magnets.] Coercive force exerted to retain magnetization is sometimes called *retentivity*.

Exp. 185. — Determine if a strong bar magnet will attract readily iron tacks through sheets of paper, glass, zinc, copper, and soft iron respectively. The attraction seems to be about the same except in the case of iron.

Soft iron may be used as a "screen" to magnetism. An inside case of soft iron may be used to protect the steel "hair spring" of watches from magnetization. [See Exp. 186 (*g*) and comments.]

Exp. 186. — Magnetic **Force Lines.** Cut a depression in a smooth piece of board just large enough to receive flatwise a flat, strong bar magnet. Cover the magnet and board with a thin glazed piece of paper, and fasten it firmly at the corners with copper tacks (Fig. 138). Sift upon the paper steel filings (from saw) and holding the whole horizontally with one hand spread out beneath, tap it gently for some time from beneath with a light hammer, letting the blow come between the outspread fingers as nearly along the "line of direction" as possible. Avoid draughts of air or heavy breathing upon the filings that after each blow they may be as much as possible under the influence of the magnet only.

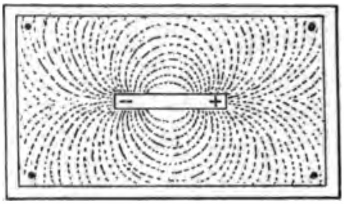


Fig. 138.

Magnetic **Force Lines** are imaginary lines, but you now have a graphic representation of them in a most beautiful picture. The axis of the earth and the equator of the earth are imaginary lines, but they are of no more importance to the sciences treating of them than are force lines to the science of magnetism. In Fig. 77 we may consider every vertical as a gravitational force line along some one of which every particle of matter in the body is urged. The *direction* of a gravitational force line is downward along the vertical.

Exp. 186 (*b*). — Suspend from a cork *A*, a plumbline and a magnetized knitting needle as shown in Fig. 139, and bring the small lead ball *b* and the north-seeking pole of the needle down in different places successively near the horizontal plane upon which the filings are arranged. In what direction is the pole urged? [In this and the succeedi chapter, by "force line" will be understood a force line of a ma-
netic field.]

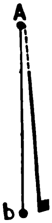


Fig
139

A **force line** is the line along which a single pole is urged. Magnetic force lines are curved.

The **direction of a force line** is the direction in which a north-seeking pole is urged. The force lines re *assumed* to come out of the north-seeking pole f the magnet, to pass round through the air (or ther medium), and to enter at the south-seeking ole, completing their circuits through the body of he magnet. Though the direction is really as much the other direction as the one according as a uth-seeking or a north-eking pole is acted upon, et to prevent confusion, ectricians have fixed the irection as determined by e tendency of the north-eking pole. We should **then think** of the force lines ot as without direction as shown in Fig. 138, but as aving the direction shown in Fig. 140.

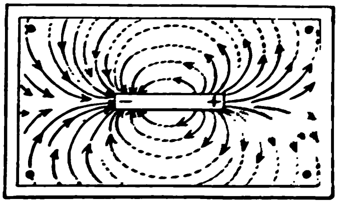


Fig. 140.

Exp. 186 (*c*). — **Fuse and nearly close one end of a glass tube b, ig. 141. Magnetize a very small sewing needle, and tie an untwisted silk thread about it, so that it balances horizontally when suspended. Place a bit of melted wax on the under side to prevent slipping. Pass the other end of the thread down through the fused end of the glass, and inverting, draw needle up as shown. Wax the thread at the top (c) of the glass tube. The glass tube prevents motion of translation. This makes a very good ordinary magnetic needle and dipping needle combined. Place the needle in different places just over the filings. Does it mark as a tangent the direction of the force lines? Try the tical plane. Try oblique planes. Examine the steel filings (mag-s) quite carefully as to the directions in which they point.**

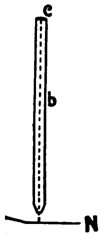


Fig. 141.

A magnetic needle free to rotate upon any axis, under the influence alone of a given field, places its magnetic axis tangent at the center to the force lines of that field, and shows also the **direction** of the force lines of the field. There are no open spaces in the field as there seem to be between the "magnetic curves" of the filings. These open spaces are due to the mutual attractions and repulsions of the little induced filing-magnets. The smallest portion of space in a magnetic field is presumed to have at least one force line running through it.

Exp. 188. — (*d*) Sprinkle in like manner filings above the poles of a horseshoe magnet, and note position and direction of force lines (Fig. 142). (*e*) Sprinkle filings above the poles of two bar magnets placed as shown in Fig. 143. Note the direction of repelled force lines. (*f*) Place as shown in Fig. 144. (*g*) Place a soft iron armature or keeper (a piece of soft iron used to cover the poles of a horseshoe magnet) in the field represented in Fig. 142 or Fig. 144, and notice whether fewer or more force lines as shown by filings pass towards and therefore through it than before passed through the same space when filled with air.

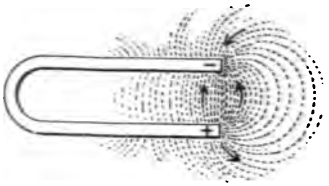


Fig. 142.

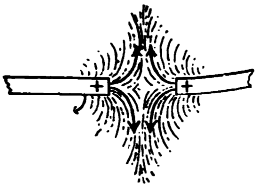


Fig. 143.

Soft iron possesses great conductivity for force lines. In other words, it increases greatly the number of force lines passing through the space which it occupies. This property is called **permeability.** The great permeay or conductivity for force lines of soft iron will ain more fully Exp. 185.

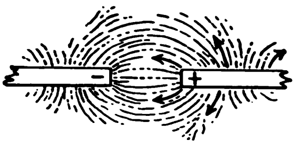


Fig. 144.

tendency of the force s is to seek the opposite , and that by way of iron rather than through air space. [See magnetic en in electrical dictionary.]

xp. 187. — Place the south-seeking pole of a bar magnet towards orth, and above its center hold the needle of Fig. 141. Pass the needle slowly north and south over the magnet and observe the dip (Fig. 145). As we carry a dipping needle from north to south and from south to north over the surface of the earth, it behaves very like this needle, its n-seeking pole dipping more as we go farther north of the equa- till near Hudson Bay it stands vertical with its north-seeking downward. As we go farther south of the equator its south- ing pole dips more and more.

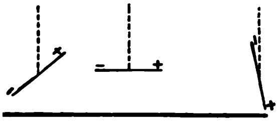


Fig. 145.

) Hold an unmagnetized bar of iron as the dipping needle points, gently rap it with a hammer. Test with needle. It has become eptibly polarized, the lower end becoming a north-seeking pole. he earth is, or acts like, *a great magnet*, having two normal s and several consequent poles. The pole near Hudson Bay is uth-seeking pole, that is, if our earth were suspended so as to te freely, and were brought near a fixed earth just like itself, Hudson Bay pole would seek the south. The magnetic axis he earth does not correspond with the geographical axis, but is ined to it. [See Exp. 178 and comments.]

xp. 188. — Determine the true geographical meridian from the itect's drawings or from other sources. Draw a line upon the e in the plane of this meridian, that is a line precisely north and h. Suspend a long magnetized knitting needle just above this , and measure the angle which it makes with the line. See that magnet or iron is near the needle.

The variation or **declination** of the needle for any given place is the angle which the needle makes with the geographical meridian at that place. Remembering that the earth's force lines pass *northward* towards the magnetic pole near Hudson Bay, that the dipping needle is tangent at its center to the earth's force lines, and that a vertical plane passing through the magnetic axis of the dipping needle passes through the magnetic axis of the horizontal needle at the same place, — we have the data for the complete explanation of declination. The declination and the inclination of the needle vary slightly from year to year at any given place. Fig. 146 shows why the declination is about 18° east in San Francisco (*S.F.*), about 20° west in Portland, Me. (*P.*), and zero at Cleveland, O. (*C*). *G-P* is the geographical pole, *M* a geographical meridian, *M-P* the magnetic pole, and arrows show magnetic meridians. Cleveland is on the "line of no declination," and the horizontal directions of the force lines are called magnetic meridians. The force lines enter the earth near the magnetic pole, which lies below the surface.

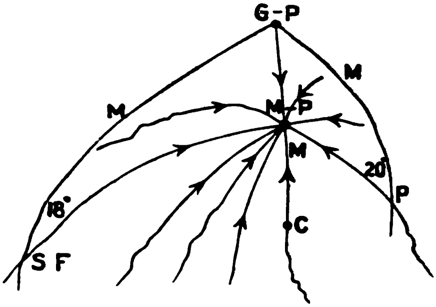


Fig. 146.

NOTE. — The subject of magnetism is by no means completed in this chapter. See Chapter XV. See also Magnetism, Amperian Currents, Astatic Needle, etc., in electrical dictionary.

QUESTIONS.

1. Why is repulsion a better test of polarity than attraction?
2. If we find a north-seeking pole at one end of a piece of stee are we sure that there is a south-seeking pole at the other end?

is a saturated magnet?

what circumstances will a north-seeking pole apparently ıer north-seeking pole?

is meant by the Magnetic Equator of the earth? How ətermine whether you stood upon it?

ır latitude by induction from the earth's field the upper · end of an iron post becomes a north-seeking pole? it be in Lat. 60° south?

se a bar magnet supports three nails, one below the other th-seeking pole, what is the polarity of the lower end of il?

force line, direction of a force line, coercive force, inclination, consequent pole, induction, permeability, magorth-seeking pole.

se we hold a bar magnet horizontally, and attach as ıs it will hold one after the other below the pole. What ffect if we place a large piece of soft iron opposite the :he upper side of the magnet? Exp. 186 (*g*) will help Remember that a field is stronger as more force lines ı it and weaker as fewer pass. Is there more or less *free* o act upon the nails while the soft iron is present?

ion some experiment which might be substituted for one is chapter. (*b*) Mention something which you have ıt magnetism "outside of school and books," either by ıservation or from those engaged in employments involv-ɔf magnetism.

CHAPTER XV.

CURRENT ELECTRICITY.

Exp. 189. — Into a tumbler two-thirds full of water, pour about one-twentieth its volume of sulphuric acid, stirring with glass rod that the bottom of tumbler may not become too suddenly heated. Stand into the acid a strip of zinc about 3 cm. wide and 4 cm. longer than the height of the tumbler. Observe the effect of chemical action. Hydrogen is set free in the form of bubbles according to the reaction, $Zn + H_2SO_4 = ZnSO_4 + H_2$. [See Chemistry.] Remove and rub that portion of the zinc which has been acted upon by the acid with a few drops of mercury, using a piece of soft leather, or a piece of cloth tied upon a stick. Immerse as before in the acid. The bright amalgam of mercury and zinc is not acted upon by the dilute acid. Nail the zinc and a similar piece of copper to opposite sides of a narrow strip of wood, reaching across the top of the tumbler. Use short nails or tacks, being sure that they do not touch one another in the wood. Inclose the bright ends of two short pieces of insulated copper wire as shown in Fig. 147, and bend the two strips under and downward, so that they may be near together and parallel, but not touching. Immerse in the acid, and observe that there is little or no chemical action. Connect the two wires and observe that the copper strip is rapidly covered with bubbles, showing that chemical action begins as soon as the wires are connected. Thinking of the sulphuric acid molecule as composed of two parts, a positive H_2 and a negative grouping SO_4, the chemi-

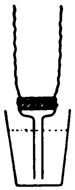


Fig. 147.

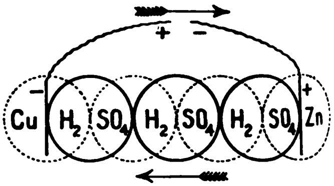


Fig. 148.

action may be represented by Fig. 148, in which the whole circles resent the original molecules, and the dotted circles the *progres-* e decomposition from right to left.

A Voltaic Cell is composed of two conductors im- ersed in a liquid which acts chemically upon one them, while they are externally connected by an ectrical conductor. The immersed conductors are lled *plates*, and the ends of the unconnected wires ading from each are called *poles* or *terminals*. The ate acted upon chemically is positive, therefore its le (*opposite end*) is negative. When the poles are nnected, the electric "*current*" is assumed to "*flow*" om the positive plate through the liquid to the nega- ve plate, and from the positive pole to the negative ole through the external conductor.

The zinc plate is "*amalgamated*" to prevent chemical action hen the "circuit is open," and to prevent "local action" when the ircuit is either "open" or "closed." By local action is meant hemical action producing a current between the minute particles f impurity imbedded in the commercial zinc and the rest of the zinc late, all going on within the liquid and contributing nothing to the xternal current.

EXP. 190. — Adjust the spring so that it will just lift the armature f a sounder. Consider this instrument as a machine upon which ergy may be expended, and do not at present give the sounder rther study. Connect one wire from the cell to one "binding st" of the sounder, using either wire. Does anything seem to ss from the cell over *one* wire to the sounder? Connect the two ires to the sounder, one to each post, and observe that something aws the armature down, overcoming the resistance of the spring. is as if *something* passed from the cell through one wire to the under, and returned to the cell through the other wire, doing work passing. Very soon the bubbles of hydrogen accumulate upon e copper plate of the cell, and the armature is drawn up by the ring, showing that the "current of electricity" is weakened.

Brush quickly the hydrogen bubbles from the copper plate, or lift the plates out of the liquid and reinsert them; the armature is drawn down again, showing that the "current" is strong enough to do directly or indirectly the work of overcoming the resistance of the spring. The bubbles again quickly accumulate, and the spring lifts the armature. Does the "current" pass through the air space before you touch the "binding post" with the wire, as the electricity produced by friction would do?

The accumulation of a film of hydrogen upon the negative plate of a voltaic cell produces what is called **polarization** of the cell. This weakens rapidly the current, partly because it must pass through this non-conducting film of hydrogen, and partly because of the tendency of the hydrogen to produce an opposite current. Efforts to prevent polarization give rise to numerous kinds of voltaic cells. The most effective method is to destroy the hydrogen set free by the chemical action, before it accumulates upon the negative plate. This is done by surrounding the plate with a liquid or solid that will react or unite with the hydrogen.

EXP. 191. — At the bottom of a glass jar about 15 cm. deep, place a large strip of thin sheet copper, *Cu*, Fig. 149, bent up at each end and having riveted to it the cleaned end of a rubber coated, No. 16, copper wire *b*. Place crystals of copper sulphate upon the copper, a few more than will dissolve when the dish is two-thirds full of water. After stirring the copper sulphate till a saturated solution has been formed, pour carefully upon it a dilute solution of zinc sulphate. This solution will float upon the other. It may be made by dissolving zinc in dilute sulphuric acid till hydrogen ceases to be evolved. Bend a heavy strip of zinc, and hang it over the edge of the jar with the lower portion below the surface of the zinc sulphate as shown. Solder or rivet an insulated copper wire, No. 16, to the

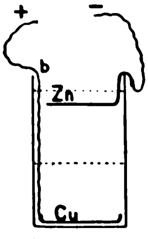


Fig. 149.

zinc. Both wires should be short, and may be lengthened by attaching other wires to them by connectors. One is shown in Fig. 150, viz., two strips of sheet copper, 1 × 3 cm., riveted at the center and open at each end. Connect this cell to the binding posts of the sounder and observe that the armature goes down *and stays down*. The zinc does not need to be amalgamated, and may be removed from the liquid when the cell is not in use.

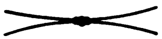


Fig. 150.

The **Gravity Cell** gives a very *constant* current, and is called a *closed-circuit* cell, because it may be kept on a closed circuit without polarization.

The chemical action in the cell may be explained thus: The copper sulphate solution slowly diffuses upward through the less dense zinc sulphate solution, and coming in contact with the zinc the principal reaction may be considered to be

$$Zn + Cu\,SO_4 = Zn\,SO_4 + Cu$$

The copper by the same progressive action through the liquid as is shown in Fig. 148 is deposited upon the copper plate. Copper deposited upon copper does not change materially the internal conditions, and hence the constancy of the current. Among the subordinate reactions going on at the same time is the oxidation of the zinc setting hydrogen free. Part of this hydrogen is entangled in the impurities upon the zinc, as the pupil will observe, and part makes its way towards the negative plate by progressive decomposition, but is prevented from reaching the plate by the following reaction : —

$$H_2 + Cu\,SO_4 = H_2SO_4 + Cu$$

The copper is deposited as before. Among the names given to the gravity cell are "copper sulphate," "blue stone," and "crowfoot." This cell is a modified form of the Daniell's cell (which see in reference books). A *battery* is usually composed of several cells connected, though one cell used alone may be called a battery. In this country most batteries used in telegraphing are composed of gravity cells.

Exp. 192. — Connect the gravity cell to the sounder by fastening one wire to one binding post, and touching the other binding post with the other wire several times, observing the force with which the armature is drawn down. (*b*) Fasten a long coil of fine insulated copper wire by one end to the free binding post of sounder, and make connection several times as before, passing the current through the coil. Does the cell do as much work upon the sounder when it it sends its current through a long wire between itself and the "machine" upon which it does work?

Resistance is the obstruction offered by any conductor to the passage of a current of electricity. No substance possesses perfect *conductivity*, that is, offers *no* resistance to the passage of a current of electricity.

The action of a cell may be compared to the action of a pump, *P*, Fig. 151, which forces water from the lowest and discharging point *A* up to the highest point *B*, the entire line *A* to *B*, including the pump, corresponding to what is within the cell. In case of the gravity cell, *A* represents the zinc plate and *B* the copper plate within the liquid. It is as if something were forced *up*, so to speak, by the action of the cell from the zinc plate to the copper plate, to flow downward through the external conductor as water would flow downward and back from *B* through *CD* to *A*. If the pipe *CA* were either longer or smaller or rougher, the current of water would meet more resistance in returning to *A*. So with electricity, if the external wire is longer or smaller, or made of not so good a conducting material, the current would meet more resistance. The upright tubes Nos. 2, 3, 4, etc., represent the fall in pressure or level due to resistance in the pipe. If the pipe from *C* to *D* were enlarged, then there would be less difference in level between No. 2 and No. 1, and there

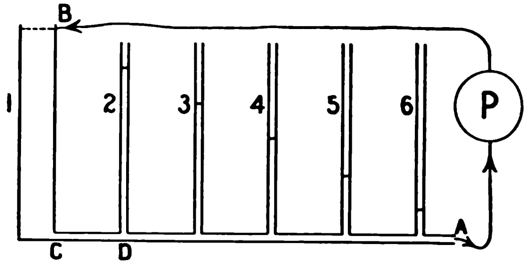


Fig. 151.

ould be more pressure in the pipe between D and A, which pres-
ıre would raise slightly the level in all the tubes between D and A.
f the pipe from C to D were made smaller, then there would be more
lifference in level between No. 1 and all the other tubes. We might
all the pressure exerted by the pump to produce the difference in
evel "water-motive" force, and the amount of water passing any
oint, as A, the current. So the "electric pressure" of the cell, or
vhatever it is in the cell which tends to produce a current of elec-
ricity, we call *Electro-motive Force.* That which corresponds to
lifference of level in water we call in electricity "difference in
otential," and the amount of electricity driven through the resist-
nce by the electro-motive force we call the *current.* The *potential*
alls in proportion to the resistance just as the water level does, as
hown by the upright tubes in Fig. 151. The difference in potential
etween any two points is the difference in *effective* electro-motive
orce between those two points.

Units for measuring Electro-motive Force (E. M. F. or simply E),
esistance (R), and Current Strength (C), will now be given. The
sistance in the whole circuit is often conveniently divided into ex-
rnal resistance (R) and internal resistance (r). When no r (small)
pears, R covers the total external and internal resistance.

A **volt** is approximately the electro-motive force de-
eloped by one gravity cell.

It is the "electric pressure" produced by one gravity cell, or it
the "difference of potential" between the plates of the gravity cell.

An **ohm** is approximately the resistance offered by
0 meters of copper wire 1 millimeter in diameter.

The legal ohm is the resistance offered by a volume of mercury
0°, 106.3 centimeters long, with a cross section of 1 square milli-
ıeter. It is understood that the current passes longitudinally
ırough all conductors, unless the contrary is mentioned. The **con-
uctivity** is the reciprocal of the resistance. If the resistance of
wire is 2 ohms, its conductivity is ½.

An **ampere** is the current produced by an electro-
ıotive force of one volt acting through a resistance of
ne ohm, or an equivalent current.

Two volts acting through 2 ohms would give a current of 1 ampere, but 2 volts acting through a resistance of ½ an ohm would give a current of 4 amperes. **Ohm's Law** may be stated mathematically as follows:—

$$C = \frac{E}{R}$$

in which C is the current in amperes, E the electromotive force in volts, and R the resistance both external and internal in ohms.

Exp. [illegible]. Amalgamate the lower half of a stout strip of zinc by dipping it in dilute sulphuric acid, and then rubbing with a few drops of mercury. Set this zinc strip loosely into a space sawn out from one edge of board as shown by modified horizontal section in Fig. 152, placing it between two rods of carbon (waste carbons from an arc light) fastened at the top between the two strips of wood. The zinc should be set so that it can be raised or lowered, but must not be set so loosely as ever to touch the carbons. Connect the carbons with a wire pressed against them by screwing one piece of wood to the other. Solder or clamp to both the zinc and the wire loop a wire to convey the current. Fill a wide-mouthed bottle a little over half full with a solution of *chromic acid* in dilute sulphuric acid, 1 volume of the sulphuric acid to 15 volumes of water. [Instead of this a saturated solution of potassium bichromate in sulphuric acid of double this strength may be used. Dissolve the bichromate after the acid has become cold. The reaction of course produces *chromic acid*.] Place the carbon and zinc plates in this liquid, and touch for a moment only the binding posts of the sounder, observing with what energy the armature is drawn down. Lift the zinc from the liquid as chemical action upon it continues after the circuit is opened. It is better to remove both zinc and carbons after you have finished using the cell for the day.

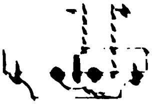


Fig. 152.

The **Chromic Acid Cell** has an electro-motive force of about 2 volts. The chromic acid checks polarization by oxidizing the hydrogen, but this oxidation does not go on with sufficient rapidity to prevent gradual polarization. The current is always stronger when the zinc is first immersed, and grows slowly but continually weaker.

This cell is often called a *Grenet cell;* and a *Plunge Battery* is composed of several chromic acid cells, the plates of which are connected to a board, so that by means of a crank they may be raised from, or lowered into, the liquid.

Exp. 194. — Place two or three rods of carbon together, and stand them into a porous earthen cup. Pack about these pulverized carbon (or charcoal) mixed with manganese dioxide. Fill the cup full, and wax over the top with the carbons projecting above. Place the porous cup in a glass dish containing a saturated solution of ammonium chloride, and stand a rod or strip of zinc into the solution outside of the porous cup. Twist about each carbon very firmly a short copper wire, and then twist the free ends of these together, allowing one to extend beyond the rest. Solder another wire to the zinc. After the porous cup is well soaked in the solution, pass the current for a moment through the sounder, and observe that the armature is drawn down promptly.

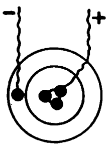


Fig. 153.

The **Leclanché Cell** (pronounced in two syllables by dealers and workmen) has an electro-motive force of about 1.5 volts. It is an open-circuit cell. When the circuit is closed the current grows rapidly weaker, because the manganese dioxide does not oxidize the hydrogen nearly so fast as it is set free by the reaction.

For *bell ringing* and other discontinuous work this cell is most excellent. It recovers from polarization as it rests, and needs little care except filling up with water occasionally. The porous cup needs no renewal. When the ammonium chloride (sal-ammoniac) solution becomes nearly exhausted it should be poured out, and the porous cell soaked in water *till it no longer smells of " ammonia."* The cell may then be " recharged " by a fresh solution of ammonium chloride and a new zinc rod, if necessary.

NOTE. — The cells above mentioned may be purchased of any dealers. There are many other cells in use besides the three mentioned in this book. See larger works and the electrical dictionary for a description of these. Pupils may manufacture cells of various sorts by using strips of different metals immersed in different liquids, as salt and water, caustic potash solution, etc.

EXP. 195. — Connect a coarse, uninsulated copper wire about 5 dcm. long to the two poles of a chromic acid cell. Dip the center of the bent wire into steel filings, and, raising it, notice that no filings *cling* to the wire. Dip again into the filings; and, lowering the zinc plate, after a few moments raise the wire.

A wire carrying a current of electricity is surrounded by an **electro-magnetic field,** or, more simply, by a magnetic field.

EXP. 196. — To determine the **direction of the force lines** in the field surrounding a wire carrying a current. Bend the uninsulated wire connecting the poles of the chromic acid cell into the shape shown in Fig. 154, and bring its plane into the magnetic meridian. Magnetize a very fine needle, and, breaking off about 4 mm. of the pointed end, tie an untwisted silk fiber (from unraveled silk ribbon) near its center. Wax the under side by means of a hot glass tube touched to wax and then to the silk. Mount this magnetic needle by passing the fiber through a short piece of glass tubing, as shown in Fig. 141. Hold this magnetic needle successively on each of the four sides of that part of the wire up which the current is to pass, and drop the zinc. Which way does the needle point for each position ?

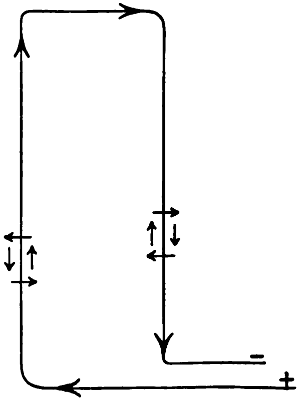


Fig. 154.

(*b*) Do the same with reference to that part of the wire down which the current passes. Observe with care if the needle points the same as before on the front, rear, right-hand and left-hand side of the wire.

(*c*) Hold the needle on top and then under the two horizontal portions of the wire. How does the needle point?

Right-Hand Rule. — *Grasp the wire with the right hand so that the extended thumb points in the direction of the current; then will the curved fingers show the direction of the force lines.*

Exp. 197. — Let some one connect the wire to the poles, covering them with a handkerchief that you may not see them. Can you now determine by the needle which way the current passes?

(*b*) Place a pivoted or suspended needle about 3 cm. long successively under and above each horizontal wire. Does it turn at right angles to the wire as the short and light needle *seemed* to do?

A magnetic needle used to determine whether a current of electricity is passing, and if so in what direction, is called a **Galvanoscope.**

We may include in the galvanoscope the wire, straight or coiled, through which the current passes to affect the needle. Any given force line produced by a current in straight wire lies in a plane at right angles to that wire. The needle, however, lying in the magnetic meridian, when currents are passed about it along this meridian, does not turn at right angles to the wire, because, though the force lines due to the current urge its axis towards the east and west line, the *earth's force lines* (horizontal component) urge it towards the magnetic meridian. According to the laws of the composition of forces, the needle takes up a position somewhere between the two positions. A current at right angles to the magnetic meridian might not only not move the needle, but might hold it more firmly stationary.

Exp. 198. — Through a coil of No. 16 insulated copper wire, made by winding carefully upon a lead pencil till the coil is about 1 dcm. long and then removing the pencil, pass a current of electricity from a gravity cell. Hold the coil horizontally, and pass the current in such a way that the flow shall be upward on the nearer side and downward on the farther side, as shown by the modified section in Fig. 155. Grasp the coil in the right hand so that the curved fingers point in the direction of the current, and hold the thumb extended. Bring each end of the coil near the north-seeking pole of a pivoted magnetic needle. One end repels and the other attracts the needle.

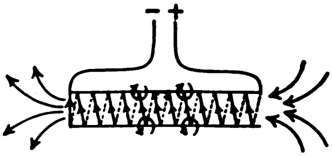


Fig. 155.

(*b*) Pass the current so that it will come down on the nearer side and go up on the farther side. Reverse the right hand as you grasp the coil, that the curved fingers may point in the direction of current. Test the coil for polarity.

Right-Hand Rule for Coils.— *Grasp the coil so that the curved fingers show the direction of the current; then will the extended thumb show the direction of the force lines that thread through the coil.*

Exp. 199. — Make a small chromic acid cell by using a beaker, with a well-fitted cork carrying below the plates and above a connected coil of fine wire. Float this cell by passing the beaker down through a hole in a large, flat piece of cork. The coil turns its axis to the meridian. Bring the north-seeking pole of a bar magnet to the north-seeking pole of coil.

A regular coil of wire through which a current of electricity is flowing possesses **polarity**, and behaves like a magnet. Such a coil is often called a *solenoid.*

Exp. 200. — Cut soft iron wire into pieces a little longer than the coil used in Exp. 198, and fill the coil with wire. Pass the current as before, and bring the north-seeking pole of the coil near the north-seeking pole of the needle. Is the needle repelled more or less vigorously than when no soft iron was within the coil?

Soft iron being an excellent conductor of force lines when placed within a coil, increases greatly the strength of the poles by preventing the leakage of force lines on the sides of the coil as shown by the

four arrows in Fig. 155. This conductivity causes the lines to run *through* the coil, to emerge at the north-seeking pole, and to enter at the south-seeking pole, greatly increasing the strength of the poles.

Exp. 201. — Hold the coil and soft iron vertically. Pass the current again, and picking up upon the lower pole a large soft iron nail, break the circuit. The nail drops. Use a very light nail. (*b*) Pull out one of the soft iron wires from the coil and observe that either pole of a heavy pivoted needle is attracted by it.

Soft iron made a magnet by a current of electricity passing about it is called an **Electro-magnet** or a temporary magnet. The iron retains its magnetism only while the current is passing. A minute trace of magnetism, however, is left after the current ceases. This is called **residual magnetism.**

The electro-magnet may have the form of the bar or of the horseshoe, but more commonly that of the horseshoe. This brings the poles near together and concentrates the force lines within a smaller field. If the observer *faces the pole*, the current must pass *anti-clockwise* about the soft iron to produce a north-seeking pole and *clockwise* to produce a south-seeking pole. Fig. 156 shows how a horseshoe electro-magnet must be wound, the wire crossing between the two arms over the connecting piece (dotted) as shown. If the horseshoe electro-magnet were bent out straight, the wire would run regularly from one end to the other as in the bar electro-magnet.

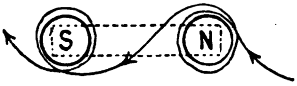


Fig. 156.

Exp. 202. — Place half of a *steel* knitting needle in the coil, and pass the current as before. Remove and test the polarity of the needle.

A current passed around a piece of steel, through an insulated wire, makes of it a permanent magnet. Stronger magnets may be made in this way by powerful currents than by rubbing with other magnets.

Exp. 203. — Connect three Leclanché cells on open circuit as shown in Fig. 157, and observe that between the cells you have a *series* of arcs. (*b*) Turn the cells about so that zincs and carbons stand connected in two rows as shown in Fig. 158. Notice that you have *multiplied* the number of arcs necessary to connect any two cells by two. Notice also that the connecting wires, if straightened out, are *parallel*, and that if the zincs and carbons were men marching with the wider front, they would be marching *abreast*. Connecting cells, inasmuch as we connect two at one time, is often called "coupling" cells, though there may be many cells in the battery.

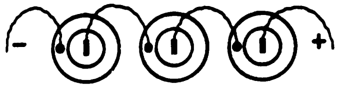


Fig. 157.

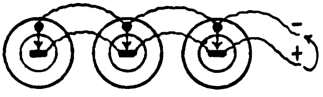


Fig. 158.

When the positive plate of one cell is connected to the negative plate of the next cell the cells are said to be connected **in series**; and when the positive plates are connected directly to each other, and the negative plates directly to each other, the cells are said to be connected in **multiple arc** or *in parallel* or *abreast*. In multiple arc is sometimes contracted to "in multiple."

Exp. 204. — Upon a horizontal base, *A*, Fig. 159, erect a hollow circle of wood *C*, having an outside diameter of about 25 cm. and inside diameter of 20 cm. The circle should be grooved on the outside to receive wire, or a flexible strip of wood may be fastened with *brass* tacks about each edge to hold the wire between. It should be mounted *vertically* upon the base. This may be done by means of square-cornered blocks, screwed to both base and circle. No iron or other magnetic metal should be used in its construction. A little below

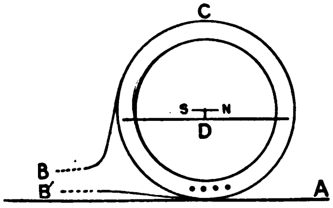


Fig. 159.

the center of the circle, fasten parallel to the base a strip of wood D. Dismount the circle, and wind carefully upon it from a spool a great many turns of fine insulated copper wire. Remount, fastening the ends of the copper wire to the bottom of two binding posts *BB'*, so that starting from the left hand binding post *B* the wire may pass *over* and *under* (in the order mentioned) the circle. Precisely at the center of the circle mount upon a sharp pivot a magnetic needle about 2 cm. long and made from watchspring. The pivot may be driven in by grasping with small pincers, and pounding upon them with a small hammer. Fig. 160 shows a modified horizontal section, explaining the mounting of the needle. Below it is a cardboard carefully graduated in degrees, and to the under side of the needle is fastened a piece of pith, through which the pivot passes freely, and from which two fine threads of glass run out precisely at right angles to the needle. These threads serve as pointers, and are made by drawing out suddenly a fine tube of glass that is red hot at the center. The needle should have a depression on the under side to receive the pivot. This may be made by softening the needle, impressing with steel point, hardening, and remagnetizing. [Sect. I. Appendix.] The graduated circle should be about 1 dcm. in diameter. The needle should be boxed in a very shoal box having a thin clear glass cover. This prevents drafts of air from disturbing the needle. The needle and pointers should be so adjusted that the pointers may each indicate the same *deflection* when a current from a *constant* battery is passed in either direction through the coil. The reading may be taken before the vibrations cease by observing the central mark over which the needle swings. The whole should be handled very carefully that, after the needle and pointers are once correctly adjusted, they may not get out of adjustment. Bring the coil into the plane of the magnetic meridian, that is, adjust so that the pointers indicate 0. Pass a current from one gravity cell in at *B*, and *over* and *under* the needle, and out at *B'*. Apply the right-hand rule for coils, and observe whether the needle follows the rule. Observe also the amount of the deflection. Pass the current in the opposite direction, and apply the rule. (*b*) Use two cells connected in series, and observe the amount of the deflection.

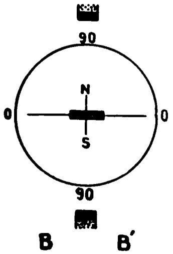


Fig. 160.

A galvanoscope provided with a scale so that the deflection of the needle may be accurately measured is called a *galvanometer*. A **Tangent Galvanometer** is so called because the strengths of any two currents passing through it are proportional to the tangents of the angles of deflection. [Sect. X. Appendix.] If from two batteries two currents passing successively through the galvanometer deflect the needle to 45° and 65° respectively, the currents or amperes are not as 45 to 65, but the second current is 2.14 times the first, the tangents of these angles being as 1 to 2.14. What is the tangent of an angle?

The coil must be kept in the plane of the earth's magnetic meridian, or in the vertical plane passing through the needle, before it is influenced by the current. A "controlling magnet," whose force lines combine with those of the earth's, may determine this plane. The needle must be *short* compared to the diameter of the coil, so that in deflection it may not pass out of a sensibly uniform field; that is, so that the lines of force may be sensibly parallel in that part of the field occupied by the needle. If the galvanometer contains a long coil of fine wire, it is called a *high resistance* galvanometer.

Exp. 205. — Make a tangent galvanometer like the last, except instead of many turns of fine wire use two turns of coarse wire, No. 8 or No. 10, with a diameter of only 10 cm. for the coil.

If a galvanometer contains only a few turns of very coarse wire, it is called a *low resistance* galvanometer.

The high resistance and the low resistance galvanometer may be combined upon the same stand by using four binding posts. By multiplying the binding posts, and carrying the wire around again after returning it to the second binding post, and again returning to a third post, etc., the instrument may be made either a *long coil* or a *short coil* galvanometer at will.

Exp. 206. — Connect two gravity cells in series through the high resistance galvanometer, and observe the deflection of the needle. Connect them in multiple arc through the instrument. Is the deflection more or less? This experiment seems to prove that it is better to connect cells in series.

(*b*) Connect as before first in series and then in multiple arc through the *low resistance* galvanometer. This experiment seems to prove that it is better to connect in multiple arc.

When the external resistance is great, connect cells *in series.* When the external resistance is small, connect cells in *multiple arc.* The reason for this will soon appear.

Exp. 207. — Connect two binding posts, *A* and *B*, Fig. 161, at the base upon a board by a very fine wire *c*, and a very coarse wire *C*. Place the central portion of the two wires parallel to the magnetic meridian, and pass a current from *A* to *B*. Hold a needle (galvanoscope) above the center and close to each wire in succession. Why does the needle turn more from the meridian when over one wire than when over the other? A galvanoscope may measure very roughly the relative strengths of currents.

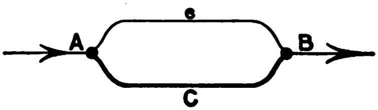


Fig. 161.

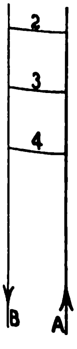


Fig. 162.

When a current divides over two or more conductors, the parts of the divided currents are called **shunt currents,** or simply shunts. The current divides *inversely as the resistances.* For instance, if the resistance in *c* is two ohms, and the resistance in *C* is one ohm, two-thirds of the current passes over *C*, and one-third over *c*. Either current is a shunt to the other.

When there are three shunts, the reciprocals of the numbers expressing the ohms in each shunt are to be taken, and the current

divides as these. For instance: between the two leading wires or "leads," Fig. 162, so large that the resistance along these between the cross wires may be neglected without sensible error, let there be three shunt wires having 2, 3, and 4 ohms resistance respectively. How will a current of 26 amperes divide over these shunts?

SOLUTION.

$$\begin{array}{llll}
\frac{1}{2} = \frac{6}{12} = & 6, \ \frac{6}{13} \text{ of } 26 = & 12 & \text{amperes over the first.} \\
\frac{1}{3} = \frac{4}{12} = & 4, \ \frac{4}{13} \text{ of } 26 = & 8 & \text{" \quad " \quad second.} \\
\frac{1}{4} = \frac{3}{12} = & \underline{3,} \ \frac{3}{13} \text{ of } 26 = & \underline{6} & \text{" \quad " \quad third.} \\
 & 13 & 26 & = \text{total current.}
\end{array}$$

To find the total resistance between two leads, knowing the resistance of each shunt, we may proceed as follows: —

(1) If the shunt wires are all of equal resistances we have, of course, only to divide the resistance of one by the numbers of shunts. For instance, if there are two shunts having 1 ohm resistance each, the *combined* resistance of the two would be only $\frac{1}{2}$ an ohm. Cells coupled in multiple arc, Fig. 158, form *internal shunts* as shown by the arrows. Such a battery has as its internal resistance only the resistance of one cell divided by the number of cells. Its electromotive force is only that of one cell. In other words, in Fig. 158 it is the same as though we had one cell three times as large.

(2) If there are two shunts of different resistances, take the reciprocals of the resistances. This gives the conductivity of each wire. Add these conductivities, and again take the reciprocal for the combined resistance. In Fig. 161 let shunt c have a resistance of 3 ohms, and shunt C a resistance of 2 ohms, we find the combined resistance as follows: —

$\frac{1}{3}$ = conductivity of c.
$\frac{1}{2}$ = conductivity of C.
$\frac{1}{3} + \frac{1}{2} = \frac{5}{6}$ = combined conductivity.
$\frac{6}{5}$ or 1.2 ohms = combined resistance.

Making the terms general, let r and r' be the resistances, then will $\frac{1}{r}$ and $\frac{1}{r'}$ be the conductivities. Adding we have $\frac{r + r'}{rr'}$ = the combined conductivity and $\frac{rr'}{r + r'}$ = the combined resistance, therefore the combined resistance of two shunts is equal to *the product of the separate resistances divided by the sum.*

(3) If there are more than two shunt wires of varying resistances, ***add the conductivities and take the reciprocal*** **for the combined resistance.**

EXAMPLES.

1. Four cells having an E. M. F. of 1.5 volts each and an internal resistance of .6 of an ohm each, give what current when connected in series through a coil having a resistance of 8 ohms? (*b*) If the same cells are connected in multiple arc, what current shall we obtain?

SOLUTION (*a*).

$$C = \frac{E}{R + r}$$

$$C = \frac{6}{8 + 2.4}$$

$$C = .57 + \text{ amperes.} \quad \textit{Ans.}$$

SOLUTION (*b*).

$$C = \frac{1.5}{8 + .15}$$

$$C = .18 + \text{ amperes.} \quad \textit{Ans.}$$

2. If we pass the current from the same four cells through a coil of coarse wire whose resistance is only .1 of an ohm, which will be better, to connect in series or in multiple arc?

SOLUTION (*a*).

$$C = \frac{6}{.1 + 2.4} = 2.4 \text{ amperes.} \quad \textit{Ans.} \quad \text{If in series.}$$

SOLUTION (*b*).

$$C = \frac{1.5}{.1 + .15} = 6 \text{ amperes.} \quad \textit{Ans.} \quad \text{If in multiple arc.}$$

3. If six chromic acid cells have each an E. M. F. of 2 volts and an internal resistance each of .9 of an ohm, what current will

they give if connected as shown in Fig. 163, through an external resistance of .6 of an ohm? [The straight wires connecting the groups in parallel or multiple arc before the two groups are connected in series, are assumed to be large that their resistances may be neglected in solving.] The E. M. F. of each group is 2 volts, while the resistance of each group is, according to the law of internal shunts, .3 of an ohm (.9 ÷ 3). Therefore we have:—

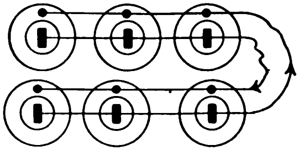


Fig. 163.

$$C = \frac{4}{.6 + .6} = 3.3 + \text{amperes. } \textit{Ans.}$$

(*b*) Is this a greater or a less current than would be obtained, if the cells were coupled in series?

(*c*) Than if cells were coupled in multiple arc?

A "mixed coupling" is sometimes better than either the series or the multiple arc connection.

4. What is the combined resistance between the leading wires represented in Fig. 162?

SOLUTION.

$$\tfrac{1}{2} + \tfrac{1}{3} + \tfrac{1}{4} = \tfrac{13}{12} = \text{combined conductivity.}$$

$$\tfrac{12}{13} = .92 + \text{ohms. } \textit{Ans.}$$

EXP. 208.—Bend a long, fine, insulated copper wire backward upon itself from the center, making it double, each half parallel and close to the other. Now wind from the bent middle a coil upon a lead pencil, and, removing pencil, test the coil for polarity while a current is passing through it.

Non magnetic coils are produced by winding the wire double. The electro-magnetic field produced by the current advancing to the center of the wire is destroyed by the returning current, which produces force lines running in the opposite direction.

A **rheostat** is an instrument containing a series of non-magnetic coils of graduated resistances.

The coils of the rheostat are connected to two adjacent segments (Fig. 164 and Fig. 165) of a thick brass plate in such a manner that any coil may be introduced into the circuit, passing from the binding-post *B* to the post *B′* by simply removing the brass peg or switch *S*. When the pegs are all in there is practically no resistance in the plate of the rheostat. When any peg is out, then the current must pass through the coil connecting the same segments as the peg connects.

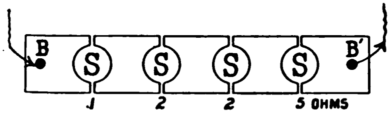


Fig. 164.

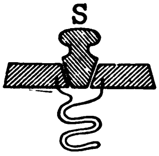


Fig. 165.

Exp. 209. Pass the current from a gravity cell through the rheostat and through the low-resistance galvanometer. Observe the deflection of the needle. Introduce by removing its peg the 2-ohm coil, and observe deflection. Now introduce the 20-ohm coil. Why is the deflection less as more resistance is introduced ?

(*b*) Place a fine coil of uninsulated copper wire in circuit with the low resistance galvanometer, arranging the coil vertically. Observe the deflection. Heat moderately the coil, and observe the effect upon the deflection.

(*c*) Treat in like manner a coil of German silver wire. Is the effect of heat more or less marked than before ?

Heat increases the resistance of metallic conductors, but affects the resistance of German silver much less than that of ordinary metals. For this reason resistance coils used in electrical measurements are often made of German silver. Heat decreases the resistance of carbon and of liquids in general. By what experiments might you prove this?

EXP. 210. — Pass the current from a constant battery through the sounder and the galvanometer, using coarse wire that its resistance may be neglected without sensible error. Do not place the sounder very near the galvanometer. Why? Note the deflection. Remove sounder and *in its stead* place the rheostat. Remove pegs from the plate till the needle is deflected just as before. Add the resistances of the rheostat that have been thrown into the circuit to replace the resistance in the sounder.

To measure the resistance in any instrument (or conductor), add the resistances in the rheostat which have exactly replaced the resistance of the instrument.

In attempting very accurate measurements this method is open to the objection that no battery gives a perfectly constant current. For such measurements a more complicated arrangement of resistance coils is used, and the apparatus, conventionalized in Fig. 166, is called **Wheatstone's Bridge**. The current flowing from *A* to *D* divides at *A*, part going by way of *B* and part by *C*. The dotted sides are practically three connected rheostats, in each of which the resistance may, of course, be varied by removing pegs shown by the small dots in the cut. The instrument or coil whose resistance is to be measured is attached at *d* to the binding posts one on either side of the opening. A galvanometer is connected between the posts *B* and *C*. When the resistance in the four sides are in the propor-

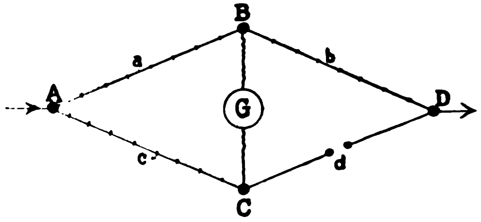


Fig. 166.

tion **a : b :: c : d**, there is no current through the galvanometer. This is easily seen by the pupil, if he will think of water flowing from *A* to *D* through two pipes, while a small cross pipe extends from *B* to *C*. So long as the pressure is the same at *B* and *C* there is no current through the cross pipe. So with the electrical current, if the potential, that is the *effective electromotive force*, is the same at *B* and *C*, there will be no current through the galvanometer. The potential at each point will rise and fall equally as the battery current fluctuates, and consequently the variation in the current does not interfere with the measurement. We have only to adjust the resistances of *a*, *b*, and *c* so that no current passes through the galvanometer, and then find the unknown quantity *d* in the above proportion. In simpler forms of the Bridge (*B C* is the "bridge" proper from which the apparatus takes its name), a straight wire of uniform diameter extends from *A* through *B* to *D*, while the point *B* on the wire from the galvanometer slides on this straight wire to vary the resistances of *a* and *b*. This variation is directly as the length of the segments cut off on each side by the sliding point *B*, and is shown by a scale immediately below the wire.

Exp. 211. — Set up two gravity cells as directed in Exp. 191, as nearly alike in every respect as possible. Connect them in series through the sounder, allowing them to remain on the closed circuit over night that they may each be in good working order for the test. Disconnect from the sounder and connect the cells in opposition through the galvanometer, that is so that the current from each tends to flow in a direction opposite to that of the other. There should be no deflection of the needle. Connect a third cell passing its current through the two cells which now act as a passive conductor. Find the resistance of the two cells by substituting for them coils from the rheostat as in the last experiment. One-half of this is the resistance of one cell. Similar cells taken from any closed circuit may be used.

To find approximately the resistance of any cell, take one-half of the resistance of two similar cells connected in opposition. Why not take the direct resistance of one cell as of any other conductor? The resistance of a cell becomes less, if its plates are made larger or if its plates are brought nearer together. How would you prove this? Cells connected in multiple arc form practically one cell with large plates.

Problem. — Find the resistances of the high resistance and the low resistance galvanometer, using a third and *low resistance* galvonometer for the purpose.

As by Ohm's law

$$C = \frac{E}{R},$$

if E is constant C varies inversely as R. But C also varies as the tangents of the angles of deflection, therefore: —

When the electromotive force is constant, the resistance varies inversely as the tangents of the angles of deflection.

Stating mathematically for two resistances R and R′ through which the same electromotive force has acted to produce deflections a and a′ respectively, we have,

$$R : R' :: \text{tang. } a' : \text{tang. } a,$$

in which R and R′ are the total resistances external and internal of the respective circuits.

Exp. 212. — Pass the current from two gravity cells used in Exp. 211, through a given resistance (s) of the rheostat and the galvanometer whose resistance is known (g), and observe the angle (a) of deflection. Increase the resistance (s′) in the rheostat and observe angle (a′) of the deflection. Call the resistance of the battery x (unknown) and find the value of x in the proportion, —

$$x + s + g : x + s' + g :: \text{tang. } a' : \text{tang. } a.$$

Compare this result with the former, when the resistance of these cells was determined by the method of Exp. 211. Expect to get only approximately similar results. [Section X., Appendix.]

Exp. 213. — Pass a current from a gravity cell in good working condition, and whose resistance has just been determined, through the low resistance galvanometer. Note the deflection. Assuming the electromotive force to be one volt, compute the current that passes through the galvanometer. Find the tangent, and by a simple proportion determine the tangent of the degree to which ¼ of an ampere would turn the needle. From points laid off at this distance successively along the tangent, Fig. 167, draw lines to the center of a quadrant graduated in degrees. The radius of the quadrant should be just equal to that of the circle beneath the needle of the galvanometer. Calibrate the galvanometer so as to read in quarter-amperes by marking upon the circle beneath the needle the figures in their proper places copied from the quadrant. This will show *very roughly* the current in amperes passing through the galvanometer. A wire of ⅓ the resistance of the coil (approximately ⅓ the length of the wire and of the same size), shunted between the binding posts, will make the divisions of the scale show amperes instead of quarters, as by the law of shunts only ¼ of the current will then pass through the galvanometer.

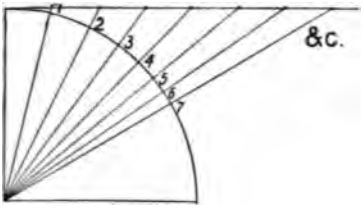


Fig. 167.

A low resistance galvanometer calibrated to read directly in amperes is called an **ammeter** (amperemeter).

Any galvanometer used as an ammeter must have a low resistance that it may not introduce into the original circuit, the current in which it is desired to measure, any perceptible resistance. The second current (passing through the ammeter) must be practically equal to the first, as it is this first current that we wish to measure. The most accurate results are obtained when the deflection is between 30° and 60°. In case of powerful currents the needle may be kept from too great a reflection by means of a properly adjusted shunt between the binding posts of the ammeter. There are numerous kinds of ammeters. A form showing the force with which a piece of soft iron is drawn into a solenoid of coarse wire is often used in measuring powerful currents. (See Exp. 221.)

Exp. 214. — Pass the current from one gravity cell through the low resistance galvanometer (ammeter). Afterward pass the current from two cells *coupled in series.* Why is not the current twice as great as at first?

(*b*) Pass the *current as before but through the high resistance (and long coil) galvanometer.* Why is the current the second time *approximately* twice as great as at first? A comparison of R and r in the application of Ohm's Law furnishes an answer.

A very high resistance galvanometer may be used to measure electromotive force (differences in potential or voltage). When such a galvanometer is calibrated so as to read directly in volts it is called a **voltmeter.** A high resistance galvanometer may be calibrated from one deflection given by a current of known electromotive force, the divisions being reduced by the law of tangents.

The electromotive force of a battery may be determined by means of a galvanometer not calibrated in volts, a given cell being used as a standard. Let E be the electromotive force of the standard cell, and E′ (unknown) that of the given battery. Pass the currents successively through the rheostat and the galvanometer, adjusting the resistance in the rheostat so that the deflections shall be equal. By Ohm's Law we have $\frac{E}{R+r+g} = \frac{E'}{R'+r'+g}$. Making in our experiment R and R′ (resistances in rheostat) large, g (resistance of galvanometer) being also large; r and r′ (resistances of standard cell and of battery respectively) may be neglected. We have only to solve the equation, finding the single unknown quantity E as the electromotive force required.

There are numerous forms of voltmeters. In those of the galvanometer type the coil usually has a resistance of from 2,500 to 5,000 ohms. Of course the magnetic field produced by the current sways the needle alike in the voltmeter and the ammeter, but when E acts through a very large external resistance R, the current is affected very little by variations in r. In this case the current varies as E varies. This is easily shown by solving two problems under Ohm's Law, in which R is large (5,000), and the same in each case, and r is small, but different in each case. The quotient expressing the amperes is practically the same. As any wire (or point) having a higher potential than another wire or point is to this extent "charged," electrostatic voltmeters or electrometers may measure voltage.

Exp. 215. — Examine an ordinary electric bell, tracing the current from one binding post to the other. Muffle the bell and watch the movements of the armature carrying the clapper, as the current from one Leclanche cell passes through the coil.

The common **electric bell** is operated by a current which enters at one binding post, passes through the coil of the electromagnet *E*, Fig. 168, thence to an insulated post *P*, thence to the spring *A* attached to the soft iron armature forming a part of the hammer, and thence out by the other binding post. When the current passes, the armature is drawn forward (towards the electromagnet), causing the clapper to strike the bell. As soon as the armature is drawn forward the current is broken between *P* and *A*; the spring *S* then draws the armature backward till the points again touch. These two movements are alternately repeated as long as the circuit is externally closed by the "push button." The points of contact between *P* and *A* are made of metal not easily oxidizable. Fig. 169 shows a push button. Fig. 170 shows an insulated post. This is kept from touching the "bed-plate" by non-conducting washers *b* *b'*.

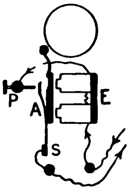


Fig. 168.

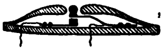


Fig. 169.

Exp. 216. — Arrange the wires from two Leclanche cells coupled in series so that by joining two free ends the bell will ring. Fastening these ends about a half-inch apart, make a rough division of various substances into conductors and non-conductors by touching the two ends simultaneously with one after the other of the following: iron, tin, glass, silver, lead, wood, gutta percha, charcoal, paraffine, cork, bismuth, zinc, flesh, platinum, iron oxide, copper, copper oxide, porcelain, any metal not yet mentioned. Dip the ends into a bit of mercury, into water, into oil.

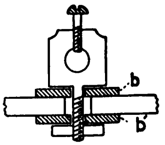


Fig. 170.

No conductors are perfect conductors. No non-conductors are perfect insulators. A current of very high potential would force itself through some of these substances which you have pronounced non-conductors, and would ring the bell through them. For instance, the high potential current from the discharging Leyden Jar forced itself through flesh, which (with a testing battery developing an electro-motive force of only two volts), you have pronounced a non-conductor. [Section XI. Appendix.]

Exp. 217. — Examine carefully a sounder with reference to giving and receiving signals upon it. Connect one pole of a gravity cell, or of two cells connected in series, to one binding post *B*, and touch the other post *B′* with the other pole, immediately separating them again. You hear *two clicks* close together. How are they produced? Suppose a strip of paper were being drawn along regularly by clock-work under the screw *b*, Fig. 171, as is done in recording instruments, you would have made upon the paper, a *dot* provided *b* were pointed. Touch the post again, but separate post and pole after about a second. You hear two clicks, but farther apart than before. If a paper were moving beneath *b* as before, a *dash* would be made upon it. *S* represents the spring, *E* the electromagnet, and *A* the armature.

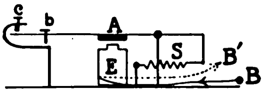


Fig. 171.

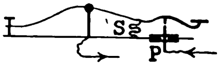


Fig. 172.

(*b*) Examine a key, noticing the insulated post *P*, Fig. 172, and the platinum point on top of it. This meets the platinum point above upon the "lever" when the lever is pressed down to close the circuit temporarily. Observe that, when more permanent closings are desired, they are made by a "switch" swung over from the side. Arrange cell, key, and sounder in circuit, and signal in succession the letters of the alphabet. Notice that there is a "space" in c, o, r, y, z, and &.

MORSE'S ALPHABET.

LETTERS.			FIGURES.
a .—	k —.—	u ..—	1 .——.
b —...	l ——	v ...—	2 ..—..
c .. .	m ——	w .——	3 ...—.
d —..	n —.	x .—..	4 ....—
e .	o . .	y	5 ———
f .—.	p	z	6 ......
g ——.	q ..—.	&	7 ——..
h	r . ..		8 —....
i ..	s ...		9 —..—
j —.—.	t —		0 ——

A **sounder** is an electrical instrument for receiving signals called dots and dashes without recording them. A dot is heard as two clicks close together, and a dash is heard as two clicks farther apart.

A **key** is an instrument for conveniently closing an electric circuit manually. In telegraphing, the operator who wishes to send a message first opens the switch. A dot is made by pressing the "button" upon the lever, and immediately relieving it of pressure, thus closing the circuit for an instant only. A dash is made by keeping the button down, closing the circuit for a longer time.

NOTE. — The pupil is advised to give no further attention to telegraphy than is necessary to understand the simple principles of the key, sounder, and relay. He should not attempt to memorize the alphabet unless he has special reasons for learning telegraphy.

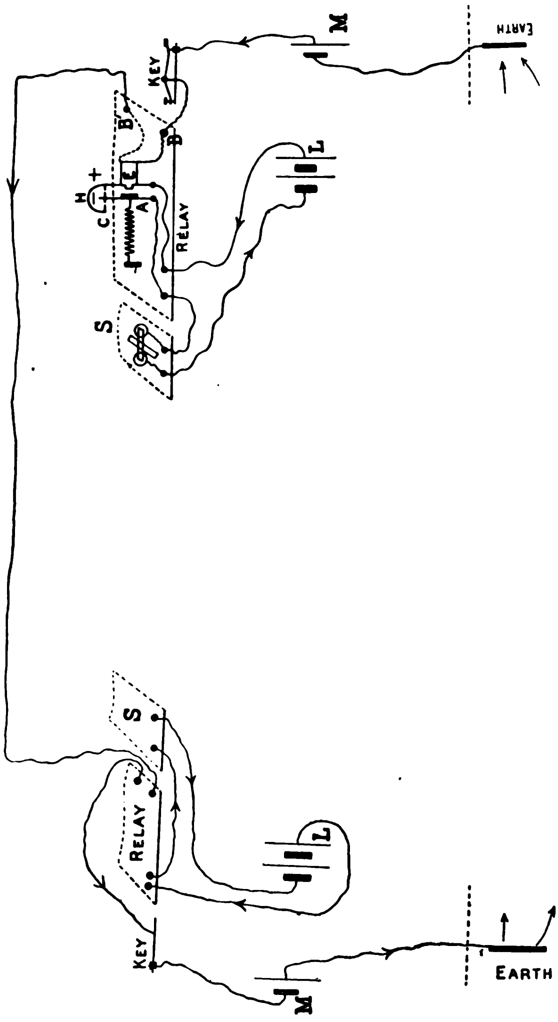


Fig. 178.

xp. 218. — Set up carefully or examine carefully after they are up, two telegraph stations as shown in Fig. 173. Trace the n line current and the local currents through the instruments. The gravity cells, two in each battery, are shown conventionalized. thin lines represent negative plates, and the shorter, heavier s the positive plates. Any kind of cells may be thus repre- ted. The current leaves the copper plate of the main line bat- r *M* as shown at the right of the figure. It passes to the insulated t *I* of the key. When the lever is pressed down (or when the tch of the key is closed) it passes on through the framework of key to one of the end binding posts of the relay (relay is shown tively enlarged). From this binding post it passes through the *E* of the relay (drawing the erect armature *A* forward towards coil), and out at the other post *B′*. The current then passes over the line wire to the second station (instruments not shown letail at this station), down to one end binding post of the relay his station, through the coil, drawing forward the erect armature, at the other end binding post, through the key whose switch is ed to the zinc plate of the remaining portion of the main line tery. From the negative or copper plate the current passes to the th (water-pipe conects well to the earth), and through the earth to the zinc plate, and out at the copper plate as before. Two s are represented in the *one* main line battery, which cells are ided between the stations. Two cells are represented in each of *two* local batteries. The arch *H* and the armature *A* of the relay n the poles of the local battery. On the forward side above, two inum points touch as the magnet produced by the main line cur- t draws the armature forward. When the main line current ses, a spring draws the erect lever bearing the armature *A* back inst an insulating gutta percha point *C*. It will be seen that the n line current does not enter the sounders *SS*. The local cur- t enters the relay (usually at one of the *side* binding posts), pass- through the arch *H* and armature *A* (i.e., the lever bearing the ature), but not passing through the coil. Whenever the erect ature of the relay goes forward, moved by the main line current, horizontal armature of the sounder goes downward moved by the l current.

The **relay** is an apparatus by means of which one current, usually eaker one, may close another and an entirely different circuit.

It may be defined as a sounder, whose arch and armature form t poles of another circuit.

As used in telegraphy the relay (called also *repeater*) has a mu higher resistance than an ordinary sounder, usually 150 ohms, whi the sounder has only about 10 ohms. To set up two stations represented, however, 30 ohm relays and 60 ohm sounders will found best. In the schoolroom or laboratory it is not necessary have very noisy sounders. This high resistance in them will preve the local batteries from "running down" rapidly, and they may b used on a closed circuit for months without any care whatever. Th main line cells act through the same resistance, as the current from them passes through both relays. It is not necessary to use relays on short circuits, but the main line current may be sent directly through the sounders. This, of course, does away with all local circuits. The advantages of "grounding" the wire are two; viz., (1) It makes a large saving in the cost of construction, and (2) It decreases the resistance one-half, as the earth has practically no resistance. The comparisons of pumps to batteries, pipes of flowing water supplied by these pumps to wires carrying currents, and the supplying lake of water to the earth, will show how any number of currents may be completed through the earth without confusion. Currents may also be completed through a common "return wire."

Exp. 210. — Pass the current from several chromic acid cells connected in multiple arc, through a very short and fine piece of platinum or iron wire. It should be raised to the white heat. Even if the cells are nearly exhausted, the temperature of the wire is sensibly raised, as may be shown by igniting a match or by touching with the finger.

(*b*) Pass the current through a short, very fine wire made of fusible metal. [See Chemistry, Exp. 121.] A minute piece cut from a shaving of the metal will do. It melts, breaking the circuit.

We may use an electric current so as to produce from it, as the chief result, **heat.** This is done by introducing into that part of the circuit where heat is desired a appropriate resistance. We may explode gunpowder b thus heating a short piece of fine wire within it. O rse the temperature is raised somewhat in all parts an electric circuit because of the resistance to the rent in all parts.

Electric **Welding,** Electric Forging, and Electric Fur- ces for the reduction of ores are already economic ccesses; and Cooking "by electricity" will doubtless on be equally successful. Many metals which before ıd to be united by brazing can now be welded by ectricity. A current of low voltage (3 volts and pward) and of great amperage (250 amperes and pward) is used. There is then no danger if the current accidentally received by the operator.

Short "safety fuses" are often placed in circuits to uard against the accidental passage of too great a urrent. These are easily replaced if melted or "burned ut."

Exp. 220. — Pass an approximately proper current through a candle power or a 4-candle power incandescent lamp. Examine lso a regular 16-candle power lamp.

(*b*) Pass the current from several chromic acid cells connected series through two small sticks of charcoal as terminals, allow- g the sticks to touch each other lightly. Examine also an arc mp.

The **incandescent lamp** contains a narrow strip of carbon (charred mboo, cotton, etc.) enclosed in glass, from which the air has been hausted. Why should the air be removed? Incandescent lamps usually set *in multiple arc*, the maker marking upon them the ference in potential (volts) between the leading wires to which y should be attached. With use the carbon becomes slowly disin rated, the particles being deposited upon the glass.

The **arc lamp** consists of two sticks of gas carbon connected to ne feeding device. The upper carbon usually forms the positive pole. This pole being hotter, burns out faster and gives more light than the negative pole. When the lamp is not in use the carbons touch, but are separated when the current passes, the upper carbon rising to the proper distance as explained according to the Brush system, by Exp. 221 and Fig. 174. Arc lamps are usually connected in series. The whole current passes through each lamp, and its voltage must be great to overcome the great resistance of the lamps. It is therefore very dangerous to receive a shock from an arc-light circuit. Incandescent particles of carbon in the form of an arc between the sticks give name to this lamp.

Exp. 221. — Pass a current from a chromic acid battery through a vertical coil containing many turns of No. 14 copper wire. Place a piece of soft iron (nail) about as long as the coil, end on, near the lower pole of coil. The iron should be drawn up into the coil.

This principle is utilized in one form of ammeter, currents being measured by the force with which the soft iron is drawn into the coil. In the Brush system the carbons are kept at the proper distance apart on the same principle. Fig. 174 shows roughly how this is done. The upper carbon is connected to the soft iron core *C* of the coil of *coarse* wire through which the main current passes. At the instant the current passes, the carbons are separated by the rising of the soft iron. The separation of the carbons increases the resistance in the main circuit *M M'*. This sends more of the current over the *fine* shunt wire *S S'*, branching off at *A*. This shunt winds about the soft iron in the opposite direction from the main current (winding only partly shown in cut), and unites at *B* with the main circuit again. The current passing in the shunt weakens the field produced by the main current, since it passes in the opposite direction. This prevents the carbon from rising too much. Both currents are shunts to each other, but two currents are often conveniently distinguished as main and shunt. A clutch holds the upper carbon when it is in the correct position, and this carbon is again and again released by the action of the shunt as the sticks slowly burn away.

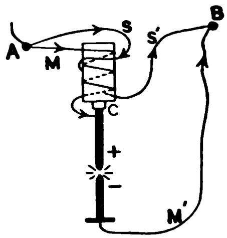


Fig. 174.

Fuse a short piece of platinum wire into one end of
; tube about 6 cm. long by 3 mm. in diameter. Heat
and gently blow a bulb upon it. Fill the
of the tube with mercury by means of a
f a short piece of large thin glass tubing
Set the bulb and lower half of the tube
5°. Inserting a wire above (almost any
oxide will do instead of platinum), push
just to touch the mercury, remove and
e tube at the top with a blowpipe. You
.ermostat.

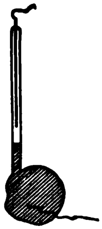
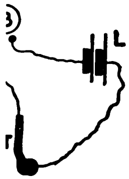


Fig. 175

a Leclanche battery *L*, a bell *B*, the ther-
an annunciator as in Fig. 176. This
form of annunciator consists of three
essential parts, an *electro-magnet E*,
a *catch-lever* supported horizontally
by a pin and carrying the armature
A, and a *drop D*. Heat gently the
thermostat. The bell rings, and the
drop falls as the thermostat closes
the circuit.



l76.

Thermostats are used to announce
and **annunciator** the breaking out of fires, or the
given space has reached any predetermined temper-
re "planted" in the holds of steamships, and are so
the pilot has notice at once of a fire and its location.
stat of Fig. 176 is changed to a push button, the
f annunciators for hotels is shown. The circuits
e push buttons or thermostats return over a common
iators contain from two to several hundred drops.
ay be placed on closed circuits, or may carry a spool-
c float, the upper connecting wire entering between
of the spool. Such instruments announce that the
s fallen to a predetermined point.

ectrical devices are becoming more numerous every
l be out of place in a text-book to attempt any enu-
m. The above instruments will serve as type-devices.
ill be mentioned under "Induced Currents."

Exp. 223. — Bore two small holes through the bottom of a glass dish, Fig. 177, by means of a small rat-tail file wet with turpentine. Through these pass two platinum wires, and wax the wires firmly about the openings to hold them and to prevent leakage. Fill the dish with water acidulated with sulphuric acid to render it a better conductor. [Section XI., Appendix.] Hang two test tubes filled with water over the ends of the wires, and sustain the tubes by screw-eyes previously waxed to the bottom of each. Pass through the water the current from two or more chromic acid cells connected in series. Bubbles of oxygen rise from the positive pole or electrode, and twice the volume of hydrogen rises from the negative electrode. We may consider that there is a *progressive* decomposition of the water (H_2O), the oxygen being negative, going to the positive electrode, and the positive hydrogen going to the negative electrode according to the law of electrical attraction. Cover the mouth of the hydrogen tube with the thumb, invert and ignite with the flame of a match. Plunge into the oxygen a live coal upon a fine splinter of wood. Oxygen being a vigorous supporter of combustion, rekindles the splinter. [See Chemistry.]

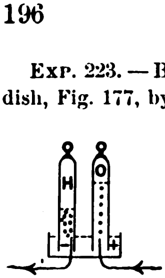


Fig. 177.

The process of separating a chemical compound by an electric current passed through it, is called **Electrolysis.**

The liquid decomposed by the current is called the *electrolyte.* The radicals (elements or groups of elements) into which the electrolyte is decomposed are called *i'ons.* The positive ion is called the *kathion* and the negative ion the *anion.* The electrode (connected to the positive plate of the battery) to which the kathion goes is called the *kathode*, and that to which the anion goes, the *anode.* The amount of decomposition is proportional, other things being equal, to the strength of the current passing through the electrolyte. An electrolytic cell employed for measuring currents forms a sort o ammeter called a *voltameter* (not to be confounded with voltmeter)

Exp. 224. — Dissolve a small quantity of potassium cyanide (ver poisonous) in a little water. Divide into two parts. To the firs add silver nitrate solution precipitating part of the silver as silve cyanide. Filter, wash with a little water, and dissolve all of th ilver cyanide that you can in the second portion of the potassium cyanide solution, stirring with glass rod. Place this last solution in a small beaker, and obtaining a globule of pure silver by fusing silver chloride and sodium carbonate together upon charcoal (Chemistry, Exp. 113), flatten and elongate this globule upon a *clean* anvil. Placing this silver in the solution as the positive pole of a chromic acid battery and a *clean* copper wire as the negative pole, pass the current through the electrolyte. The wire is plated with silver.

(*b*) Examine an electrotype plate from a series of which the ordinary school text-book is printed.

Electroplating is the process of covering any conducting surface with some metal deposited from a solution of its salt by means of an electric current. The substance to be plated (for obvious reasons) is placed upon the negative pole.

The *progressive* decomposition through the electrolyte, when the bath is a solution of silver cyanide ($AgCN$), may be represented by Fig. 178. Silver cyanide is continually formed by the union of the radical CN, set free at the positive electrode with the silver forming this electrode. The strength of the solution is thus kept constant, and as much free silver is deposited upon the copper electrode as unites with the cyanide radical from the silver electrode. Compare Figs. 178 and 148. The metals most commonly employed for the purpose of plating other metals are copper, nickel, silver, and gold. The bath in each case is of course a solution of some salt of the given metal. Many alloys of base metals are first plated with copper before being plated with the desired metal.

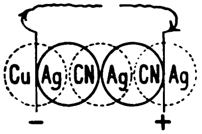


Fig. 178.

Electrotyping is a species of electroplating. The process is as follows: —

(1) The type is set.
(2) An impression is taken upon wax.

(3) The letters in depression in the wax are covered with powdered graphite, thoroughly tamped into every minute space. Graphite is a good conductor; wax is not.

(4) The wax is then hung upon the negative pole in a bath of copper sulphate and the circuit closed.

(5) When the shell of copper is sufficiently thick, it is removed and supported by metal on the reverse side.

(6) The plate is then mounted on wood to the height of the type.

NOTE. — Stereotyping, though mechanically similar in some of its processes to electrotyping, involves the use of no electricity whatever.

EXP. 225. — Set two strips of lead, the more oxidized the better, into a strip of wood, *B*, Fig. 179, and immerse in very dilute sulphuric acid. Pass a current for a few minutes from a chromic acid battery (several cells in series) through the cell, as shown. The plates, which at first were each equally covered with lead oxide (PbO), gradually assume the condition shown. The oxygen passes to the positive plate (electrode), changing the lead oxide upon it to lead dioxide (PbO_2), while metallic lead is left and deposited upon the negative plate. There are intermediate and subordinate reactions which need not be mentioned. Hydrated lead sulphate formed in charging renders the liquid milky. Notice the difference in luster of the plates. Disconnect the battery from the cell. You have a *storage cell* charged. Connect the wires of this cell to the binding posts of an electric bell. It rings. Pass the current through a galvanoscope (or galvanometer), and prove that the discharging current is in the opposite direction from the charging current. Place

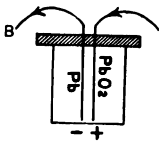


Fig. 179.

a closed circuit, and observe that, as it discharges, the urns to what is now the *positive plate* of the cell, as ie change in luster.

age Cell, called also a *secondary cell* in distinc- the ordinary Voltaic cell, which is called a ell, is an electrolytic cell, and is charged by is.

ige is of potential energy and not of electricity. It is as oxygen were "lifted up," so to speak, from one plate to ind gave out energy in returning somewhat as a stone uld do. The chemicals of the cell, in returning to their lition, give out the same electrical energy that was used sing them. We can not recover *for useful work* all of this the efficiency of a storage cell is 80 per cent, it will er cent of the electrical energy used in charging the cell. n. × 8 in. × 8 in. there may be stored energy equivalent power working for one hour.

shows a strong plate manufactured by the American mpany. The plate is composed of a stout lead frame are curved strips of sheet lead in that there is room for expansion uckling" when the plates are (charged). Many positive and ates are set alternately into a sin- positives being connected above , and the negatives on the other. the internal resistance a minute an ohm. The electromotive force ell is about 2 volts, and the cur- connected by a coarse, short wire,) amperes. Some storage plates of lead applied to them before they are charged.

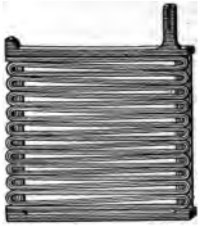


Fig. 180.

. — Examine a worn out dry cell, cutting out part of the tween its plates. Place a piece of wet blue litmus upon l.

alled "**dry cell**" is only a cell in which the liquid has ed by some solid material placed between the plates. It

may be a primary cell or a secondary cell as the maker wishes. Dry cells have not been sufficiently perfected, so that their durability can be relied upon. They are very convenient for temporary use on open circuit in portable apparatus.

Exp. 227. — **Bend two pieces of uninsulated copper wire (No. 18), about 3 dcm. long, each into the shape shown in Fig. 181. By threads about 5 dcm. long suspend each wire parallel to the other. Let the ends *M M′* dip into four little cavities cut with a half-inch chisel in a smooth board upon which is mounted the support for the threads. Fill each cavity with mercury. Let the two at the end *M* be as close together as possible, only a thin layer of wood separating them. Make the same true of the two at *M′*. Place the wires about 5 mm. apart. Standing at the end *M* looking along the paralled wires, connect by a long bent wire *W* the left hand cup of mercury at *M* with the right hand cup at *M′*. Drop the zinc of a *fresh* chromic acid cell, and connect the poles of the cell to the two remaining cups of mercury as shown in Fig. 182. Observe any movement in the suspended wires.**

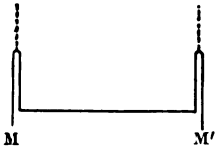


Fig. 181.

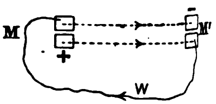


Fig. 182.

(*b*) Remove the wire *W* and connect the two cups at *M′* by a short bent piece of copper wire. Place the parallel wires about 1 mm. apart, but not anywhere touching. Drop the zinc of the cell and place the poles in the two cups at *M*. Observe any movement of the suspended wires as before.

Conductors carrying parallel currents running in the same direction attract each other. Conductors carrying parallel currents running in opposite directions repel each other. Two intersecting conductors carrying currents tend to rotate till they become parallel with the currents flowing in the same direction. A study of the force lines about each wire will explain this action.

INDUCED CURRENTS.

Exp. 228.—Roll up a piece of thin cardboard into a hollow linder about 6 cm. long with an inside diameter of about 1 cm. ip one end with the scis-rs, and spreading out the gments fasten them with ass tacks so as to hold e cylinder, *C*, Fig. 183, right upon a board about 1 m. long by 1 dcm. wide. From the nding post *B* (which may be simply a brass tack), wind several indred turns of a very fine insulated copper wire (No. 30) about the linder as regularly as possible. Bring the wire to the binding st *B′*. Connect these binding posts to a delicate gavanoscope This may be made by mounting the needle shown in Fig. 141 in a thin case of wood chiseled out of wood. The glass tube *b*, Fig. 184, should rise from the center of the thin-walled wooden frame. About this some three hundred turns of the fine wire should be wrapped longitudinally. Wind the wire half on each side of the glass tube. This will help hold the tube in position. It is best set with the untwisted silk fiber within, the needle being attached and raised to its proper position after the wire is wound. Magnetize strongly a steel rod, loosely fitting to, and about a third longer than the cylindrical coil. Plunge this gnet suddenly, with its positive pole downward, into the coil, and serve the direction in which the needle turns, and that the direc-n of the *induced* current is *anti-clockwise* in the coil as shown by arrow No. 1. Does the needle remain deflected while the mag-t stands quietly within the coil?

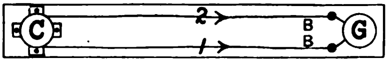


Fig. 183.

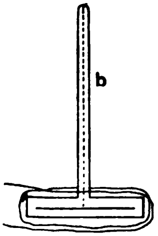


Fig. 184.

(*b*) Suddenly withdraw the magnet, and observe that the induced rent passes clockwise in the coil as shown by arrow No. 2. [The dle of the galvanometer must be far enough away so that it may t be directly influenced by the movements of the magnet.]

When the force lines which pass through a closed il are *increasing*, an induced current passes *anti-clock-*

wise in the coil, *the observer looking in the direction of these force lines.*

When the force lines which pass through a closed coil are *decreasing* an induced current passes *clockwise* in the coil, the observer looking in the direction of the force lines.

When the force lines threading the coil are not varying, no current passes.

We may just as well vary the number of force lines threading the coil by moving the coil as by moving the magnet. It is a little more convenient in studying the law of direction for induced currents to keep the coil stationary, but most machines for producing induced currents move the coil to vary the force lines within it.

Exp. 228. — (*c*) Suddenly plunge the negative pole of the magnet into the coil, and see if the rule applies. Imagine yourself looking upward in the direction of the force lines threading the coil.

(*d*) Suddenly withdraw the negative pole, and apply rule.

Exp. 229. — Stand a coil of No. 16 wire into the coil of Fig. 183, and connect with this inside coil a chromic acid cell in such a way that when the current passes it will make the polarity of the lower end of the coil positive. Drop the zinc plate of the cell, and observe the needle of the galvanometer. Apply the rule for the direction of induced currents.

(*b*) Suddenly disconnect the wires, and observe that the needle swings in the opposite direction.

(*c*) Connect and disconnect, making the lower pole of the coil negative. Imagine yourself looking upward in the direction of the force lines when applying the rule.

(*d*) Fill the inner coil with soft iron wire, and observe with how much more force the needle turns. Does the needle remain deflected while the current continues to pass or after the current has fully ceased passing? Observe that when the force lines are increased the current in the outer coil passes in the opposite direction from that in the inner coil. When a current is used as the source of the induced current, it is more convenient and suggestive to use the terms indirect and direct for anti-clockwise and clockwise.

We have for induced currents in coils this general **Law of Direction.** *When the force lines threading the coil are increasing, the induced current in the coil is anti-clockwise or indirect. When the force lines threading the coil are decreasing, the induced current in the coil is clockwise or direct.*

EXP. 230. — Connect a coil *C having a soft iron core*, a galvanometer or galvanoscope *G*, and a cell as in Fig. 185. Observe which way the needle turns. Push the needle back to 0 and place some obstacle to prevent its turning in the same direction again. Suddenly disconnect one wire at the cell, and observe that the needle turns temporarily in the opposite direction.

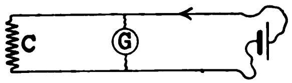


Fig. 185.

(*b*) Remove the galvanometer, and, connecting and disconnecting again, notice that there is no spark when you connect, but a very bright spark when you disconnect.

Self-induced currents are called **Extra Currents.** The extra current induced on closing a circuit flows in the opposite direction, and tends to oppose or retard the current. The extra current induced on breaking the current flows in the same direction as the original current, and tends to prolong and strengthen it.

Notice in the cut that when the circuit is broken at the cell the extra current flowing in the same direction in the coil will pass in the opposite direction through the galvanometer. The greater the number of turns of wire in the circuit the greater will be the extra current. Pendent gas burners utilize the spark produced by a "spark coil" set directly into the circuit with from four to six Leclanche cells.

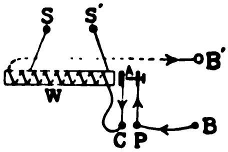


Fig. 186.

Exp. 231. — **From a binding post B, Fig. 186, carry an insulated wire (No. 16) to the bottom of an insulated post P (similar to that in the electric bell.) Arrange a light armature upon a spring, forming a "circuit breaker" C (similar to the hammer of the electric bell, only very much lighter and of the shape shown). From C carry the wire around (two layers) a close bundle of soft iron wire W about 8cm. long. Bring the wire back to the binding post B'. Around** this *primary coil* of *coarse wire* **wind a secondary coil of very fine** insulated wire **(No. 24 to 30). Make several hundred turns, and** fasten the ends to the **side poles S S'. Fasten two very small tin** cans, one each to S and S', **by means of wires soldered to the cans.** Arrange **platinum contact pieces at A, and adjust the screw so that** the "circuit breaker" **will vibrate rapidly when B and B' are con**nected in a circuit **with one chromic acid cell. Take hold of the tin** handles attached to S S', **and connect the circuit through B and B'** from the cell.

An ordinary **Induction Coil** is an apparatus for converting by means of induction, a current of low electromotive force or low potential passing through a small resistance, into an *alternating* current of high potential passing through great resistance. This secondary current has a much greater physiological effect than the primary. Why?

On coils used for medicinal purposes are often as many as ten or more "side" binding posts. The first and second are shunted or connected respectively to P and C. When the handles are connected to these posts the body receives only the "extra current" from the primary as the "circuit breaker" breaks the circuit, just as the galvanometer did in Fig. 185. The secondary wire starts at post No. 1, is wound part way on, is returned to No. 3, wound again and returned to No. 4, and so on to No. 10. Why is the effect greater if we receive the current through 1 and 10 than when we receive it through 1 and 3?

Exp. 231 (*b*). Pile up in a small shallow box alternate layers of ifoil 8 × 25 cm., well separated by paraffined paper of larger size. is paper must be without blemishes or holes rough which electrical contact could take ace. Let the odd numbered sheets of foil oject about 4 cm. on one end, and the even mbered the same distance on the other end the paper. Set a binding post through the eets at each end, and connect wires *P'* and ', Fig. 187, from them to *P* and *C* respectively figure 186. This box forms a Leyden jar or condenser. [See xp. 167 and comments.] Connect to *S* and *S'* each a short coarse ire, and bring the blunt, smooth ends within about 3 mm. of each her. Now pass the primary current, and observe the sparks that ss through the air between the coarse wires. This shows the very igh potential of the secondary current.

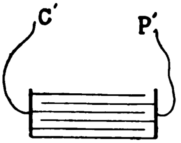


Fig. 187.

Induction coils such as have been described with or without con-nsers are often called **Ruhmkorff Coils.** With the condenser ey are often colloquially called "spark coils." They must, how-er, be carefully distinguished from the "spark coil" upon the imary (*C*, Fig. 185), which gives its spark by self-induction, and utilized in the circuit of the pendent gas burner. In "multiple ectric gas lighting," Ruhmkorff coils are usually employed instead static electrical machines to force the current across the high sistance of the gas jets, producing in the gas (dielectric) a spark hich ignites it. Indeed, the induction coil proves that current ectricity of very high potential is identical with static electricity.

Exp. 232. — Ignite a gas jet, perforate a card, make a Geissler's be glow, and perform other so-called static electrical experiments ith the high potential current from the induction coil.

Induction coils have been made containing from three hundred five hundred miles of wire in the secondary coil, and giving arks forty inches and more in length. **Transformers** are "in-rted" Ruhmkorff coils in which the primary wire is long and fine, d the secondary wire is short and coarse. By means of trans-rmers alternating currents of high potential (from an alternating namo) and small current strength may be transformed into cur-nts of great strength having small difference in potential.

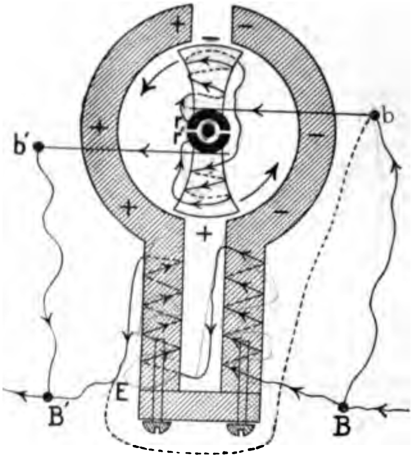


Fig. 188.

Exp. 233. — Between the poles of a horseshoe electromagnet, Fig. 188, mount delicately a piece of soft iron upon a horizontal axis as shown by modified and superimposed sections. From *r*, one of the two brass semi-rings insulated from the axle, and shown in the *front* section, carry an insulated wire (No. 24) about the soft iron making the upper end a negative pole, if the current should enter through the upper semi-ring or *segment.* Return the wire to the other semi-ring *r'* after winding properly about the lower end. [These insulated segments form the *commutator.* The rotating coil with its soft iron core is called the *armature.* The fixed electromagnet is called the *field magnet*]. At *b* and *b'* fasten copper strips or *brushes* reaching to the commutator as shown. Connect *b* to *B* and *b'* to *B'*. Lift one of the brushes, so as to break the shunt circuit through the armature, and pass the current from one chromic acid cell around the field magnet in the direction of the arrows. Disconnect the cell. A little residual magnetism remains in the soft iron core of the field magnet. Connect *B* and *B'* to the delicate galvanoscope, Fig. 184. With the finger whirl the armature in the direction of the two curved arrows, observing the direction of the current through the galvanometer. Now turn the armature slowly one-quarter of the way around at a time, and apply the rule for the direction of induced currents to the coil of the armature. Consider the force lines from the field magnet as running horizontally. Notice that while the current is *alternating* in the armature, it is made to run continuously in the same direction through the brushes and around the field magnet by means of the commutator.

Does the current pass in the same direction over the wire *b B′* as represented by the arrow or in the opposite direction? Your apparatus is a dynamo with two-poled armature. [The commutator segments for the best results need to be adjusted by twisting slightly to the right. See Appendix, Section I, 18.]

A **Dynamo,** or Dynamo Electrical Machine is a machine for *transforming* mechanical energy into electrical energy by means of magneto-electrical induction.

There are a great many kinds of dynamos. A dynamo with two-poled armature would be practically worthless because of its low efficiency. Ours is a *shunt* or shunt-wound dynamo. If we should disconnect *B* from *b*, and should carry the wire emerging from the coil of the field magnet at *E* back to *b*, as shown by the dotted line (instead of carrying it onward to *B′*), we should have a *series* wound, or a series dynamo. Were the two segments of the commutator insulated, entire rings side by side, the field magnet being either a permanent magnet or a "separately excited" magnet (that is, magnetized by some other current than the current from the dynamo), we should have an *alternating current* dynamo. The old-fashioned magneto-electrical machine is an alternating current dynamo. Compound wound dynamos are also used.

Exp. 234. — Pass a current from one chromic acid cell in at *B* and out at *B′*. The armature should whirl rapidly in the direction of the curved arrows. Why? Explain by using force lines. The explanation from the polarity of the soft iron is easier, but not so useful in helping to an understanding of an ordinary dynamo or motor.

(*b*) Reverse the current. The armature still whirls *in the same direction.* Why?

(*c*) Connect *B* and *b′*, also *B′* and *b*, reversing the current through the armature but not through coil of the field magnet.

A **Motor,** or an Electro-Motor, is a machine for *transforming* electrical energy into mechanical energy by means of electromagnetic induction.

A dynamo may be used as a motor or a motor as a dynamo. There are, however, differences in detail according as a machine is to be used as a dynamo or motor. Motors, of course, may be *shunt* or *series*. A motor with a two-poled armature would possess no practical value, because of its low efficiency as written above.

Exp. 235. — Examine a large dynamo as to the following details, some of which may be obtained from the electrical engineer: — (1) Winding of the armature. (2) Revolutions per minute of the armature. (3) Shunt or series wound? (4) Difference of potential between its terminals. (5) Resistance between its leading wires. (6) Current which it maintains. (7) Rate of development of energy (horse-power).

The unit of electrical power is the **Watt,** or volt-ampere. It is the power developed when a current of one ampere flows with an electromotive force of one volt. A current of 3 amperes flowing with an electromotive force of 2 volts would give 6 watts.

The equation for electrical power is: —

$$C\,E = W \text{ (watts)}$$

Substituting from the equation representing Ohm's Law, we have as other convenient equations,

$$C^2 R = W$$

$$\frac{E^2}{R} = W$$

We also have,

746 watts = 1 horse-power.
1,000 watts = 1 kilowatt.

The **dynamo** has generally replaced all other "generators" of electricity in furnishing the current for motors, electric lighting, electroplating, charging storage cells, etc. Its introduction has caused a somewhat similar revolution to that brought about by the introduction of the steam engine.

Note. — The wires leading from an electric generator (dynamo in motion, Voltaic cell, etc.), have electrostatic charges even before the poles are closed. The identity of current electricity and static electricity is shown by the measurement of the potential of such wires by an electrostatic voltmeter, that is, by an electrometer. We are ow prepared to see that there is but *one* electricity. Current elec-ricity developed by Voltaic cells was formerly called Voltaic or Gal-anic electricity.

THERMO-ELECTRIC CURRENTS.

Exp. 236. — Take a strip of sheet copper about 3 dcm. × 2 cm. Mount this upon a similar strip of zinc by bending together the ends, making a firm contact. Leave the two strips in the form of a parallelogram, whose opposite and longer sides are about 1 cm. apart. Mount a long and light needle between the two strips, and place the parallelogram in the magnetic meridian. Heat one of the junctions.

If a circuit be made of two metals, and one of the junctions be heated, a current of electricity will pass in the circuit. The metals which will best give this current are antimony *A* and bismuth *B*. Fig. 189 shows bars of these metals alternately arranged soldered at the points of contact. If the lower joints be heated as shown, a current passes in the wire from the antimony to the bismuth if the circuit be closed. Such an arrangement is called a **Thermo-pile** instead of a thermal battery. Its efficiency being only about 20 per cent, the principal use of the thermopile is as a *differential thermometer*. Very many bars are often used. The direction of the current when the junctions *opposite* the wires are heated, is easily remembered by the order of the letters. Of course, if this junction is cooled the current is reversed. The apparatus will show very slight changes of temperature by being connected with a delicate galvanoscope.

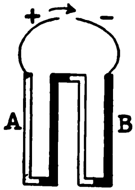


Fig. 189.

QUESTIONS.

1. If 10 cells, each having an E. M. F. of 1.5 volts, and a resistance of .6 ohms, be connected in series through an external resistance of 4 ohms, what will be the current?

2. If the same cells are connected in multiple arc through a resistance of .1 ohm?

3. If the same cells are connected, two multiple groups in series?

4. Fifty incandescent lamps, each with a resistance of 100 ohms, hang in multiple arc between two leading wires. What is the combined resistance between the "leads"?

5. There are three separate resistances between two leading wires of 50 ohms, 20 ohms, and 5 ohms respectively. What is the combined resistance?

6. A galvanometer has a resistance of 100 ohms; what must be the resistance of the non-magnetic coil shunted between its binding posts that one-fifth of the current may pass through the galvanometer?

7. Define constant battery, Voltaic cell, polarization, resistance, volt, ohm, ampere, watt, galvanoscope, residual magnetism, series, multiple arc, shunt current, conductivity, rheostat, potential, ammeter, relay, storage cell, induced currents.

8. What is the "Right Hand Rule" for a single wire? (*b*) For a coil?

9. A current of 372 amperes flows under an E. M. F. of 8 volts. How many horse-power is developed? (*b*) How many if the current is 8 amperes and the E. M. F. is 372 volts.

10. The combined resistance of three shunts is two ohms. The resistance of the first shunt is 4 ohms, of the second 5 ohms. What is the resistance of the third?

11. What are non-magnetic coils, and where are they used?

12. What advantage has the Wheatstone's Bridge over the rheostat? Explain.

13. What other term have we for *effective* E. M. F.?

14. How would you connect two gravity cells having each an internal resistance of 10 ohms to get the greater current through an external resistance of 60 ohms?

15. Draw a plan for ringing, from room A, a bell in room B. (*b*) Set one bell [diagram] in each room, and connect so that push button in A rings bell in B, and button in B rings bell in A. Use one battery, only three connecting wires, and do not allow both bells to be rung by one button.

16. Connect two thermostats with battery bell, and two "drops" of the annunciator, showing plainly the connections.

17. Why is a storage cell called a "secondary cell"? (*b*) Why is a cell confessedly moist, called a "dry cell"?

18. Why will a given current passed over or under a magnetic needle at right angles not move the needle? (*b*) Will a current at right angles ever move the needle? Explain.

19. Mention five experiments upon which the comments exceed the proof offered in the experiment. (*b*) Five in which the experiment suggests to you other and further comment.

20. Mention a good experiment which you have performed, or which you have found in some other text-book, that might be substituted for one used in this chapter.

21. Taking the definition of the ohm as given in this book, what is the resistance of 1000 m. (1 kilometer) of copper wire 1 mm. in diameter? (*b*) Of 6 kilometers 4 mm. in diameter? [The resistance is inversely as the cross section, or inversely as the square of the diameter.]

22. Taking the specific resistance *referred to copper* [Note, Section XI., Appendix], what is the resistance of 2 kilometers of iron wire 6 mm. in diameter? (*b*) Of 500 m. of German silver wire .2mm. in diameter? (*c*) Of 100 m. of platinum wire .5mm. in diameter? (*d*) Of a brass rod 5m. long and 3 mm. in diameter?

23. A 60-ohm sounder is wound with copper wire .2mm. in diameter. How long is the wire?

24. A wire whose specific resistance *referred to copper* is 3, has a resistance of 10 ohms and a length of 1 kilometer. What is its diameter?

25. A galvanometer of 5000 ohms resistance would require how long a German silver wire .1mm. in diameter?

CHAPTER XVI.

LIGHT.

Note. — The word "light" is used in Physics in two senses: (1) as the direct cause of the sensation, and (2) as the effect or sensation. If the irregular molecular motion in a body emitting radiant energy is smaller, the energy manifests itself to the senses as heat. If this motion is greater it is manifested as light, heat being always present with light, but not *vice versâ*. [See Kinetic Theory of Heat.] Bodies at or above the red heat emit light, that is, produce radiant energy capable of causing the sensation of light. Bodies which are sources of light are called self-luminous, or simply *luminous*. Examples of these are the sun, the fixed stars, white-hot particles in flame, and white-hot bodies, large or small, anywhere. Such bodies produce the vibratory motion called radiant energy in the ether about them; and the ether, which is supposed to fill all space, even the intermolecular spaces in the most dense bodies, communicates this vibratory motion outward in all directions. This radiant energy is partly absorbed by ponderable bodies (principally as heat), is partly reflected, and is often partly transmitted to the ether beyond. A single line or *ray* of light coming to us from the sun may be thought of as vibrating in segments at right angles to its direction, and *progressively* from one end (the sun) to the other (the earth). This vibration might be compared to that of a vertical line of molecules in jelly after the top of a tall jelly-dish has received a "complex jar." The vibrations in the ether which produce the sensation of light are more like those of a highly elastic *solid body* than like those transferred by a fluid. Lines of radiant energy manifesting itself as heat may be conveniently spoken of as "heat rays."

Considered separately, that department of Physics which treats of light is called **Optics.** In the causative ense, light may be defined as a vibratory motion in ther capable of affecting normally the optic nerve.

A *ray* of light is a single line of light. A *beam* of light is a collection of several parallel rays, and a *pencil* of light is a collection of rays converging to, or diverging from, a point. Rays from the sun are sensibly parallel at the earth.

Exp. 237. — Obtain a piece of ordinary window glass, a piece of ground glass, and a thick piece of mica (or three other bodies of which these are types). Try to look through each at the flame of a candle. Cleave off as thin a piece of mica as possible, and look through it.

Transparent bodies transmit light readily, *translucent* bodies less readily, and *opaque* bodies do not transmit any light. Transparent substances, if very thick, become translucent. Translucent substances, if very thick, become opaque. Opaque substances, if very thin, become translucent, or even transparent. No line can be sharply drawn between these three kinds of substances. [Bodies transmitting "heat rays" readily are called *diathermanous.* A clear crystal of common salt is one of the most diathermanous substances known. Bodies like alum, glass, water, ice, etc., which do not transmit radiant heat readily, are called *athermanous.* See comments. Exp. 148.]

Exp. 238. — Darken the room, and admit a beam of light through a small opening. Observe its path as traced by the dust. Notice that nothing can be seen between the particles of dust, though this space is filled with light. (*b*) Look into one end of a small, bent rubber tube, while the other end points towards the window, or towards illumined objects. Nothing but darkness is observed. Straighten the tube. Light and the objects from which the light comes are seen. To render an object visible, light from that object

must enter the eye. To produce normally the sensation of light, rays must enter the eye. A ray of light, crossing a dark and dustless room, looked at from the side, would be invisible.

In a homogeneous medium, ***Light travels in straight lines.***

EXP. 239. — Suspend a smooth ball about 4 cm. in diameter on a level with the flame of a very small candle, and receive the so-called "shadow" (which is really the section of the shadow) upon a paper screen. Observe that there is a darker center, *A*, Fig. 190, with a lighter portion, *B B′*, surrounding it. Make several pin-holes in the screen, some in each portion of the section of the shadow, and look backward through them at the luminous body, that is at the flame. It is invisible from any portion of *A*, but is partly visible from any portion of *B B′*.

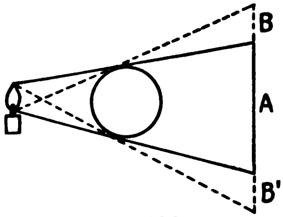


Fig. 190.

A **shadow** is the space from which the rays of light from a given luminous or illumined body are wholly or in part shut out by the interposition of an opaque body. That space from which all the rays are excluded is called the *umbra*, and that from which only part of the rays are excluded is called the ***penumbra***. Shadows are geometric solids, and are to be thought of as having three dimensions, and not as measured by "square measure."

If the luminous body were a point, how would it affect the penumbra? The sun is very many times as large as the moon. What is the shape of the moon's umbra?

Velocity of Light. Roemer, a Danish astronomer, first determined the velocity of Light. He found it to be about 186,000 miles per second.

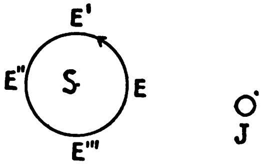


Fig. 191.

In Fig. 191 let *J* represent Jupiter with the nearest of his four large moons. This moon is eclipsed (passes behind Jupiter) at each revolution. Roemer found that if he began the measurements when the earth was at *E*, nearest to Jupiter, the intervals of time between successive eclipses increased very perceptibly till, when the earth reached *E''*, farthest from Jupiter, the sum of the "increases" was about 16.5 minutes. From *E''* around to *E* again the intervals decreased till the sum of the "decreases" was equal to about 16.5 minutes. He then came to this conclusion, that it took light 16.5 minutes to cross the earth's orbit from *E* to *E''*, a distance of about 185,000,000 miles.

Improvements in mechanism, by which exceedingly short intervals of time may be measured with accuracy, have enabled physicists not only to confirm Roemer's conclusions as to the velocity of light in space, but to determine its velocity in different media. For example, *light travels more slowly in water and in glass than in air*, and more slowly in air than in a vacuum. The latest investigations make the velocity of light *in vacuo* about 186,330 miles or 299,860 kilometers per second.

Exp. 240. — Close one eye and hold a pencil vertically a short distance from the other eye. Move the pencil away till it is held at arm's length. Observe whether the lines drawn from the extremities of the pencil to the eye make a larger or smaller angle at the eye. (*b*) Hold the pencil stationary at arm's length, and look at it first with one eye and then with the other. Observe the two positions upon the wall against which the pencil seems to be projected. Imagine lines drawn from these two positions to the pencil. Is the angle at the pencil larger or smaller if the pencil is nearer the eyes ?

The **visual angle** is the angle at the eye formed by two lines drawn respectively from two opposite and extreme points of a given object. This angle is larger as the object is nearer.

Parallax is the difference in direction of a given object as seen from two standpoints. The parallax is greater as the object is nearer, becoming 180° when the object lies on the straight line joining the two standpoints. The fixed stars are at such enormous distances from us that most of them show no parallax even when looked at most favorably from opposite sides of the earth's orbit. None of them show any visual angle (that is, any disk), even when examined by the aid of the most powerful telescope.

INTENSITY.

NOTE. — By intensity of illumination is meant the amount of light received per unit area by any given surface. By intensity of light at the source is meant the amount of light emitted by a unit area of the luminous body. Astronomers call this the "intrinsic brightness." In ordinary photometry, by the intensity of a given light is meant the *quantity of light* which the luminous body (or flame) emits compared to the quantity which the standard light emits. The relative size of the two flames or luminous bodies is not considered. In this latter sense we shall use "candle power," or simply "power" for intensity, reserving the term "intrinsic brightness" for the true intensity of the source. "Intensity of light" in a general sense is often used for "intensity of illumination," especially where the substance illuminated is thought of as both receiving and giving out (by reflection or transmission) light. Unit time is always understood in estimating intensity.

EXP. 241. — Prepare a strip of board 2 m. long by 15 cm. wide, graduated lengthwise in centimeters. Set four candles close together upon a block of wood, and one candle upon another block. The candles should be carefully selected as to the size of the wicks, etc., that each may have the same illuminating power. Prepare a slide *S*, Fig. 192, composed of a block of wood to which a piece of paper, having an oiled spot in the center, has been tacked. Place this slide upon the center of the graduated board, the paper at right angles to the length of the board. Darken the room by drawing the curtains, and adjust the board by rotating horizontally till each side of the oiled spot is equally illumined by the light which still enters the room. Light the candles, placing the single one at *A* and the others at *B* on opposite ends of the board. The oiled spot looks darker on the side receiving more light. Why? Move the slide *S*

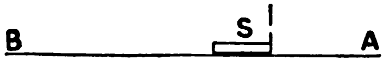


Fig. 192.

till the oiled spot is equally illumined on each side. Compare now the distances of A and B from the slide. The apparatus is called **Bunsen's photometer.**

(*b*) Replace A with a standard sperm candle [of the size known as "sixes" (six to the pound), which burns 120 grains per hour], and replace B with a gas-jet, utilizing a rubber tube to bring the gas to the burner. Arrange the slide till the oiled spot is equally illuminated, and compute the candle power of the gas-jet. In place of the gas-jet the flame of a lamp may, of course, be used.

Law of Intensity. *The* **intensity** *of illumination is inversely as the square of the distance from the source of light, and the* **powers** *of the lights necessary to produce equal illumination are as the squares of the distances of the lights from the surface illuminated.*

The comparison of the powers of different sources of light can be made only approximately. The standard varies in power according to the length of the projection of the wick, the condition of the air in which it burns, etc. The gas flame not only varies with varying pressure and quality of gas, but sends out slightly more light in some directions than in others.

Flames of the same size, as is well known, do not necessarily give the same light. Indeed, often the smaller luminous body gives more light, because of its greater intrinsic brightness, that is, the greater intensity of the light emitted. This is measured by the quantity of light emitted by one unit of surface.

Given that "Light travels in straight lines," and we can easily prove mathematically the Law of Intensity as affected by distance. Light coming from a luminous point, and passing at a distance *one*, through an orifice whose diameter is *one*, falling upon a screen whose distance is *two*, would be spread over four times the area which it fell upon in passing the orifice. The intensity therefore would be only one-fourth as great. Making the terms general by using the distance x instead of *two*, we have at the distance x for the intensity $\frac{1}{x^2}$.

EXP. 242. — Procure an old-fashioned camera (or make a camera from a paper or wooden box painted black inside). Remove the lens from the front, and fasten a blackened card with a pin-hole in the center over the large orifice. Upon thin white paper or ground glass, I, Fig. 193, receive the image $B'A'$ of some object AB, as the flame of a candle, or as a house illuminated by sunshine. The image is best seen if the head is covered with a dark cloth, so as to exclude the light from the side I of the receiving screen, while observing the image.

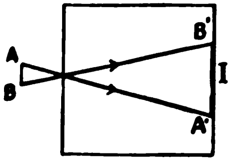


Fig. 193.

A real and inverted image of an object may be formed by allowing the light from the object to pass through a small orifice.

A **real image** is one *from which*, when it is seen, *rays of light come* to the eye.

A **virtual image** is one from which, when it is seen, rays of light *seem to come* to the eye.

Images formed by ordinary mirrors are virtual, not real. A real image is really there where it seems to be. A virtual image seems to be there, but is not really there. The rays of light come *as though* they came from it, but they do not.

If you write upon the board any given letter, as E, and continue to write a large number of E's upon and near the first, you will soon apparently have no E's there, though you have written many. Only a blur of chalk is apparent. Could you remove all but the first, or all but a few of the first, you would soon have your picture or image of E apparent again.

Analogous to this the image $B'A'$ is formed by a process of exclusion. Every ray of light from a point imprints a real image of that point upon any screen upon which the ray falls to be reflected again. Rays passing outward in all directions, innumerable in number, from any point, are all shut off by the perforated card, save a few which form the image. When the orifice is much enlarged, the image disappears, being covered by such a confusion of superimposed images of other points, that we can recognize neither it nor those images which cause the confusion.

Images of the sun are often formed upon the ground by the small openings in the dense foliage above. A perforated card gives a very interesting image of the sun during a partial eclipse.

REFLECTION.

Exp. 243. — In a darkened room reflect a beam of light from a polished surface, rotating the surface upon different axes so as to throw the reflected beam in various directions. Observe that the greater part of the light is reflected according to a definite law. ABP of Fig. 194 is called the *angle of incidence*, and PBR the *angle of reflection*. MM' is the reflecting surface, and PB the normal, or perpendicular, to that surface. [For many experiments under light a darkened room is necessary, the darker the better. While this experiment does not require a very dark room, it is much more impressive in such a room. To introduce sunlight, some form of the "*porte-lumière*," shown in Fig. 195, is necessary. The apparatus consists of a mirror, M, fastened by the hinge, H, to the tube T, which revolves horizontally, and is painted black on the inside. This tube is set in the wooden frame CC', closing the opening formed by the raised window. The string S varies the angle between the mirror and the tube to suit the varying positions of the sun. Revolving the tube T also helps to "catch the sun." The end O of the tube is closed at will by plugs having orifices of different sizes and shapes. For darkening the room, see Section I., Appendix.]

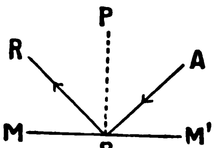


Fig. 194.

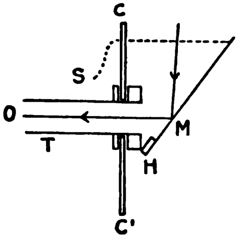


Fig. 195.

Law of Reflection. *The angle of reflection is equal to the angle of incidence, both lying in the same plane perpendicular to the reflecting surface.*

Exp. 244. — Hold a white smooth card as a reflector of a beam of light in a dark room, and observe (1) that part of the light is reflected upon the wall of the room according to the law, (2) that part is scattered by a diffused reflection *apparently* not according to

the law, and (3) that part of the light is *transmitted* or allowed to pass through the card.

(*b*) **Reflect in the same way by a piece of glass. Observe whether more or less light is reflected compared with the amount transmitted as you make the angle of incidence greater.**

(*c*) Reflect from a black card. Is more or less light reflected than from the white card?

(*d*) **Reflect several times from mirrors placed one after the other along the broken line of light, and observe whether the illumination upon the wall is any less strong than when the wall is illuminated without any reflection, or after a single reflection.**

(*e*) **Reflect the beam into a deep glass jar. Fill the jar with smoke (from touch paper), and reflect again, observing the pronounced difference when the jar is filled with smoke.**

Diffused Light is light scattered by reflections from rough surfaces, or by multiplied reflections from foreign particles in otherwise transparent media.

No surfaces are perfectly smooth. Transparent bodies are made translucent by roughening the surfaces (as ground glass), or by rendering the inside in any way not homogeneous. Whenever light falls upon transparent or translucent bodies, part of it is reflected, part is absorbed (and converted principally into heat), and part is transmitted. Opaque bodies absorb and reflect light, but transmit none. Black bodies absorb more light and reflect less than white ones. [See Exp. 148 and comment.] More light is reflected and less absorbed as the angle of incidence becomes larger.

We see objects by diffused light, which is often called "irregularly reflected light." Were it not for diffused light, the sunshine would reveal only the objects upon which it fell, either directly or after reflection according to the law. Shadows would be "dense," and objects in them invisible. "Regularly reflected light," or light reflected from perfectly smooth surfaces, would not reveal to us the reflecting surfaces. Perfect mirrors would be invisible, revealing not themselves, but images of the objects in front of them.

Note. — Except when the eye is considered as a camera, this book will treat the pupil of the eye as if it were only of sufficient size to admit a single ray of light from a given point. Of course, from any point seen, a slightly diverging pencil of light enters the eye. See the "picture cuts" in larger works.

Exp. 245.—Mount a piece of a broken mirror, *M*, Fig. 196, vertically upon the table by means of two blocks. Set a large pin, *O*, as the object. At *A*, in line with the image *I*, set the pin *A*. Set another pin, *B*, at random, and the pin *C* in line with *B* and the image *I*. Mark the position of the mirror, remembering that the reflecting surface is *behind the glass*, and then, removing the mirror, prolong the lines *A O* and *C B* till they meet at *I*. Measure *M I* and *M O*. (*b*) We have also the simple geometric proof shown in Fig. 197. Let *E* be the object. Reverse the arrowheads, and let *A B* be the diameter of the pupil (last note), then will *E′* be the image.

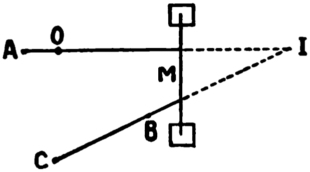


Fig. 196.

Images formed by plane mirrors are (1) virtual, (2) erect, (3) of the same size as the object, (4) as far behind the mirror as the object is in front of it, and (5) reversed with reference to the object, as the letter is the reverse of the type with which it is stamped.

Exp. 246. — Place a mirror horizontally and with the eye at *E*, Fig. 197; hold an upright twig (or a pencil) erect on the opposite side of the mirror. Why is the image of the twig *apparently* "inverted"? Having the Law of Reflection given, the explanation is very easy. Draw a figure similar to Fig. 197, explaining why the right hand seen in a vertical mirror seems to be the left, and *vice versâ*.

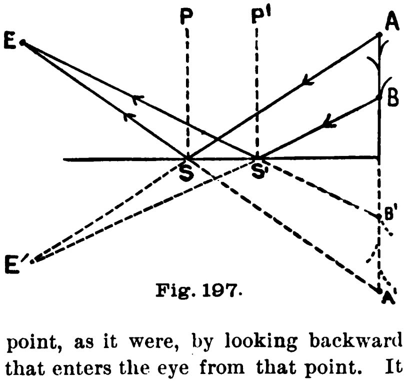


Fig. 197.

Virtual images cannot be caught upon a screen, because they have no existence except in the imagination. The eye sees a point, as it were, by looking backward along the line (ray) of light that enters the eye from that point. It matters not how many directions the ray (because of reflection or other causes) may have taken, the eye sees the point in the opposite direction from that taken by the ray as it enters the eye. For example, in Fig. 197 the eye "thinks it sees" the point *A* in the direction *E S*, that is, at *A'*. The same is true of the point *B*, which is seen as though it were at *B'*, with no mirror intervening. The same reasoning applies to all other points seen. In a loose sense this image is sometimes spoken of as an inverted image, but it is not a true inverted image. If the mirror is turned to the vertical, leaving the twig in the same position (erect), the "turning about" will be seen to be lateral, like that of the letter compared to the type that stamps it, or like that which makes the right of the object seem the left in the image formed by all vertical plane mirrors.

NOTE. — In all section work under light, real rays should be drawn as continuous lines, and the directions indicated by arrowheads. Imaginary rays and perpendiculars should be dotted, as shown in Fig. 197. A uniform rule in class work is very helpful. Every distinct portion of a broken ray should have an arrowhead.

Multiple images and images of images may be obtained by placing mirrors at angles with each other. How many images can you obtain if the mirrors are at an angle of 90°? of 60°? of 45°? [See Kaleidoscope in larger works.] Parallel mirrors give very many images of the object placed at the end of the tube (which they form) and opposite the eye. Metallic mirrors give only a single image, but ordinary glass mirrors give also several fainter images, if the observer looks obliquely. [See refraction.]

EXP. 247. — Let rays of light from the sun, the rays from which are sensibly parallel, fall upon a concave[1] mirror, as shown in Fig. 198. Suspend by a wire a small, opaque, flat body, and find a point, *F*, in front of the mirror where the body is brilliantly illuminated by the reflected rays.

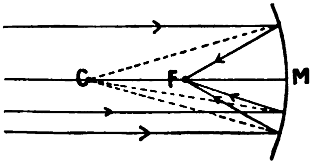


Fig. 198.

(*b*) Hold the bulb of the thermometer at *F* for a moment, and observe the effect. [Consider the second part of this experiment as a continuation of EXP. 148.]

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[1] By concave and convex mirrors in this chapter, spherically concave and convex mirrors are meant.

The point *C*, the center of the sphere of whose surface the mirror is a part, is called the center of curvature. The perpendicular from the center of the mirror passes through the center of curvature, and is called the *principal axis.* Of course all perpendiculars from the mirror pass through the point *C* along the radius of the curve. A point on the principal axis half way between the center of curvature and the mirror is called the *principal focus.* The regular Law of Reflection applies to concave mirrors. All guiding perpendiculars are to be drawn from the center of curvature. Do the reflected rays stop at *F*, if there is no screen there to stop them ?

When the **concave mirror** is only a very small portion of the surface of the sphere of which it is a part, *rays of light falling upon the mirror parallel to its principal axis are reflected to the principal focus.*

Reflections from concave mirrors exhibit the following type cases :—

I. When rays parallel to the principal axis fall upon the mirror as in Fig. 198.
II. When the source of light is at F. (I. reversed.)
III. When the source is at C.
IV. When the source is on the principal axis beyond C.
V. When the source is on the principal axis between C and F. (IV. reversed.)
VI. When the source is on the principal axis between F and the mirror M.
VII. When the source is a point not on the principal axis.
VIII. When the source of light is not a point, but a body of very sensible size, and not at so great a distance as to send to the mirror from each point of its surface sensibly parallel rays.

With a point as the source of light, let the pupil construct diagrams representing cases II. to VII. inclusive. Represent in each case three rays of light coming from the point, and reflected by the mirror. Apply carefully the Law of Reflection, guiding the reflected ray in each case by a dotted perpendicular. Do not curve the line representing the mirror too sharply, but give your arc a radius about four times as long as itself. Mark carefully C and F upon the principal axis before drawing the rays of light.

Exp. 248. — Mount a small lighted candle upon an inverted whi dish, and place the whole as the object, *AB*, Fig. 199, in front of concave mirror beyond its center of curvature. Look approximately along the principal axis towards the mirror and observe the image *B'A'*. [Case VIII.]

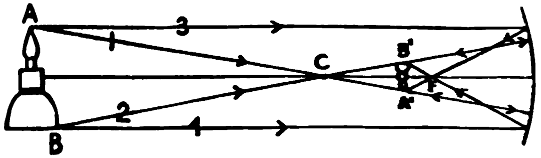


Fig. 199.

(*b*) Move the candle nearer between *C* and *F*, and standing back farther find an enlarged inverted image out where the object was before. These images are more distinct, if the room is darkened.

Concave mirrors may form real and inverted images of objects. The two points in front of a concave mirror occupied respectively by an object and its real image are called *conjugate foci.* Each is a conjugate focus with reference to the other. If the object is placed at either of the conjugate foci, the real and inverted image appears at the other focus. If the object is at the farther focus the image is minified, if at the nearer focus the image is magnified.

Two points will locate the image. Therefore, to construct the image : —

From two points, for example, *A* and *B*, Fig. 199, at or near the extremities of the object draw lines *1* and *2* representing rays passing through the center of curvature. These rays, of course, will be reflected straight backward from the mirror through *C*. The images of these points will, therefore, lie in these lines respectively. Again draw from the same points rays *3* and *4* parallel to the principal axis. These rays will be reflected through the principal focus *F*. Drawing these reflected lines we locate the two points of the image, at their respective intersections with the two former lines. The

Image may now be drawn to the proper scale in the proper place. Every ray of light from A that strikes the mirror will be reflected through A'. From A', therefore, rays will enter the eye of the observer *as though they originated at A'*. Of course the observer must stand farther from the mirror than A', and at not too great a distance from the principal axis to see the image directly. All real images may be thrown upon a screen. Draw the construction lines, and locate properly the image formed by (*b*) of Exp. 248. Any illumined body, as a bouquet of flowers, may be used for an object.

Exp. 249. Hold a concave mirror near the face, and observe the image formed by the mirror.

(*b*) Hold any small object near and in front of the mirror.

Concave mirrors form *virtual, erect,* and *magnified* images of objects placed between the principal focus and the mirror.

In explanation of Exp. 249, let A, Fig. 200, be a point upon the forehead, and B a point upon the chin, and E the eye. The point A' in the enlarged virtual image is located by the intersection of the line of sight (prolonged behind the mirror), with the prolonged radius drawn from C through A. The point of incidence I must be so located that the angle of incidence shall equal the angle of reflection. In like manner the point B is located at B'.

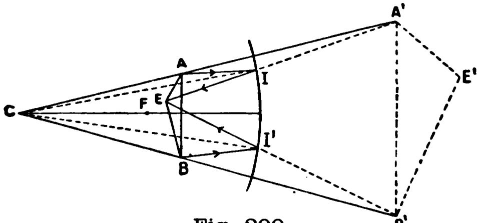


Fig. 200.

Exp. 250. — In a darkened room reflect from a convex mirror two parallel rays of light. Draw a diagram showing from what point the reflected rays would *seem to come* should they enter an eye whose pupil was large enough to receive them both.

(*b*) Look into a convex mirror.

The focus of a **convex mirror** is virtual, therefore it can form no real images. The images formed by convex mirrors are always *virtual*, *erect*, and *minified*. Fig. 200 reversed will explain (*b*) of the experiment.

Parabolic mirrors *of whatever size* reflect all rays parallel to the principal axis to the principal focus. Rays originating at the focus are reflected parallel to the axis. Parabolic mirrors are therefore used to "throw the light along the track" from the headlight of the engine. The light is placed at the focus. Distorted mirrors, as polished bowls of spoons, produce distorted images. For the subject of Total Reflection see, under Refraction, the "Critical Angle." [See Mirrors, Caustic, Aberration, Sextant, in larger works and in the cyclopedia.]

REFRACTION.

EXP. 251. — Procure an elongated dish, such as is shown in Fig. 201. A wooden tank with one glass side, and the opposite side painted black answers best. Let a ray (or beam) of light from the sun or from a candle shine over the edge, passing along the line *AIB*. Fill the tank with *clear* water, and observe that the ray now takes the broken line *AIC* nearer the perpendicular *PI*.

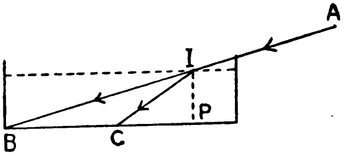


Fig. 201.

(*b*) Place a coin *A*, Fig. 202, at the bottom of the tank, so that the ray of light which reveals the nearest point takes the direction *AIE* to the eye at *E*. Lower the eye towards *E′* till the coin is out of sight, and fill the tank carefully with water, not moving the coin nor the position of the eye at *E′*. The whole of the coin becomes visible again as though it were now at *A′*. The line of light from *A* now passes over the broken line *AIE′*, bending as it emerges at *I* from the perpendicular *PI*. Notice that in each case the perpendicular is *drawn in the advanced medium*.

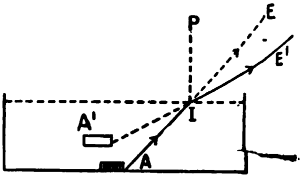


Fig. 202.

, a beam of sunshine into the water perpendicular to its
ɜs the ray bend any as it enters the water? [Physicists
ght travels less rapidly in water than in air.]

lefraction. *Passing obliquely from a medium
ht travels more rapidly into one in which light
rapidly, a ray is bent towards the perpendicu-
assing obliquely from a medium in which light
rapidly into one in which light travels more
ɜ ray is bent from the perpendicular.*

— To find the amount of refraction. Prepare a tank
1 in the last experiment, except let the inside dimen-
t 4 dcm. high, 4 dcm. wide, and 4 cm. from the front
ss to the rear and dark side. The tank may be sawn
e plank, the back painted dark, and the whole made
y means of white lead upon which the glass is buttoned
ft wooden buttons screwed to the plank. Side pieces
led to the plank to prevent its warping. Glue upon the
a square piece of stiff paper as large as the front of
th a graduated circle, as shown in Fig. 203. Cut out
ore glueing upon the
o graduated quarters,
egrees marked *outside.*
ɜ joining the points
e horizontal, when the
l. Fill the tank with
xactly to this horizon-
ı *dark room* reflect by
ɜ mirror clamped to a
a ray (beam) of light
y the *porte lumière*),
ll strike the surface of
iquely and precisely at
. Examine carefully
he ray *AIC*, noting the
and *C*. *AID* is called
incidence and *CIE* the
ıction. The extended perpendicular *DE* is called the

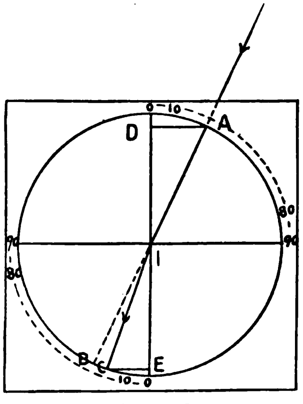


Fig. 203.

***normal.* Measure the line *DA* drawn at right angles to the normal in millimeters. This line is the *sine* of the angle of incidence. Measure *CE* the sine of the angle of refraction. Divide *DA* by *CE*.**

The **index of refraction** is the ratio of the sine of the angle of incidence to the sine of the angle of refraction. This is constant for any two substances, whatever be the angle of incidence. The index of refraction for air into water is about as 4 : 3, or, expressing the ratio by the quotient, as we express specific gravity, 1.33+. The index for air into the following is approximately: crown glass, 1.5; flint glass, 1.6; diamond, 2.5.

If the ray passes from water into air, of course the index is as 3 : 4, or ¾. The pupil will notice that the refracted ray is spread out and slightly colored. Rays giving the sensation of violet color are refracted (bent) most, and the "red rays" least. Accurately, the index must be given for a ray of definite color, as, for instance, a ray which forms some definite line of the spectrum. An index given for a line near the center of the spectrum is often called a *mean* index. The *absolute index* of refraction is the index for the ray passing obliquely from a *vacuum* into the substance, and differs only slightly from the index when the ray passes from air into the substance. From a table of absolute indices we may find the relative index for any two substances (the ray passing from the less refractive into the more refractive) by dividing the larger absolute index by the smaller. [Appendix Section XII.]

EXP. 253. — Hold a glass prism with its refracting angle, *A*, Fig. 204, downward. With the eye at *E* look obliquely through the side and see some object above at *O*, apparently located at *O'*. [We will study the coloring of the image later under Dispersion. Consider refraction only at present.] Explain, using the Law of Refraction, why the image is seen at *O'*. The difference in direction between *O I* and *I'E* is called the *Angle of Deviation*.

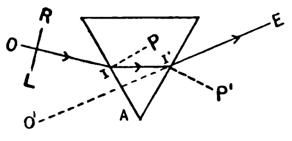


Fig. 204.

Did the triangle represent a triangular swamp, or rough piece ground difficult to march over, were *R L* an army marching in the ection indicated, would the army be marching in the same direc- n on emerging from the swamp, if both the right (*R*) and the left) wings, composed of equally good troops, marched as well as they uld ?

Light travels less rapidly in glass than in air, and for this reason e ray is bent. Were a boy to run against time " across a rectangular field om *A* to *B*, Fig. 205, one half of which ld is plowed ground difficult to run pon, would he run straight along the iagonal *A B?* Why not? Would the roken line along which he runs be ma- rially different if he runs from *B* to *A?*

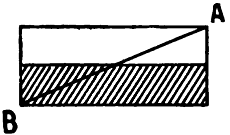


Fig. 205.

A ray of light passing between two points takes a ourse over which it can travel in the shortest possible me, and with the least expenditure of energy. For is reason, whenever the ray passes obliquely into any her medium in which it travels more or less rapidly, changes the direction of its course.

Exp. 254. — Place a fine wire, *A B*, Fig. 206, behind a piece of ss, and look at it obliquely through the glass.

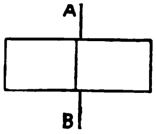
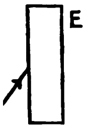


Fig. 206.

Draw a section showing the path of a single ray it comes from some point, *A*, Fig. 207, on the re through the glass to the eye at some point, Locate the point as seen by the eye at some int, *A′* (not shown in the cut). "Dot" and ter the guiding perpendiculars, remembering that they are drawn in the *advanced* medium. Apply carefully the Law of Refraction, calling the index for plate glass $\frac{3}{2}$, and guessing as nearly as you can at the amount of bending.



ig. 207.

Objects looked at obliquely through a plate with parallel faces suffer a slight "lat- al displacement." The emerging ray passing obliquely rough such a plate is parallel to the incident portion.

Having the index of refraction, we may accurately trace a ray of light obliquely through any medium of whatever shape by remembering the relationship of similar parts of similar triangles. Let Fig. 208 represent a crown glass prism, whose index of refraction is $\frac{3}{2}$ (in air). To find how much the ray is bent at *I* and *I′* we proceed as follows: —

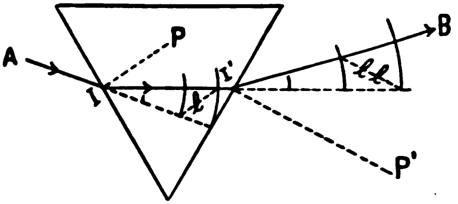


Fig. 208.

Draw in the advanced medium a dotted line representing the path of the ray if it were not bent. Lay off upon this two radii in proportion as indicated by the index of refraction. With these radii strike from *I* as a center the two parallel arcs *toward the perpendicular* (as the ray bends). Draw the guiding parallel *l* from the end of the shorter radius, and draw *II′* for the true path of the ray. Again, let a dotted line straight onward from *I′* represent the ray if it were not bent at *I′*. Lay off upon it two radii as before in proportion, but not necessarily of the same absolute length as before. Draw the arcs, but this time from the perpendicular (as the ray bends). Draw the second guiding parallel, *l l*, and draw *I′ B* for the true path of the emerging ray. If the section of the more refracting medium is too small, the guiding parallel *l* may be drawn between arcs outside on the other side of the normal. Beginners will do well to think of "the normal" as extending on both sides of the incident surface, and of "the perpendicular" as extending only on one side and forming one-half of the normal.

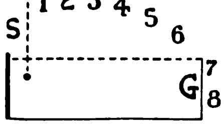


Fig. 209.

Exp. 255. — Fill the tank of Fig. 202 completely full of water. Suspend a small white pebble by a fine thread, *S*, Fig. 209, waxed to it. Let the pebble hang just below the surface, as far from the glass side *G* as possible. Remember that the pebble is seen because of rays of light coming from it and entering the eye. Look at the pebble more and more obliquely, as shown by positions for the eye, 1, 2, 3, etc. A small incandescent light may take the place of the pebble to emphasize the teaching of this experiment.

Fig. 210 should be thoroughly studied in connection with this last experiment. Let the tank be half closed by the cover *KI*, the other half of the water surface being open. Let a source of light be placed at *L*, *L′*, etc., successively. At some point, *F*, the angle of refraction for the ray incident at *I* will be 90°; viz., *AID*, for the incident angle *FIL*, emphasized by the triple curve. If the source of light be now placed anywhere in the "corner," that is, in the wedge *FIK*, as at *H*, the light cannot emerge from the more refractive medium, but is "totally reflected" internally, as shown by *IE*. The angle of incidence *HIL* is equal to the angle of reflection *LIE*.

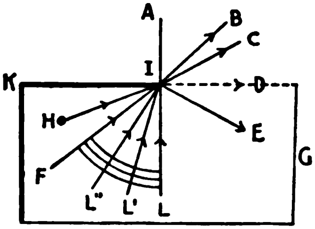


Fig. 210.

The **critical angle** is the incident angle *in the more refractive medium*, whose angle of refraction is 90°.

Total reflection takes place whenever a ray is incident in the more refractive medium at an angle greater than the critical angle.

The critical angle for water and air is about 48°, and for glass and air about 38° for flint, to 41° for crown or plate. A ray may be turned at right angles, not only by a mirror at an angle of 45°, but by taking advantage of the principle of total reflection. Fig. 211 represents an isosceles prism, the rays striking the internal surface at an angle greater than the critical angle for glass. The rays passing normally into and normally out of the prism are not refracted. There is always some internal reflection, even when the critical angle has not been reached. The reflection called "total" is not absolutely perfect, but there is a very slight diffusion and loss of energy.

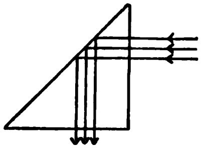


Fig. 211.

Examples of "total reflection" may be seen by raising a tumbler nearly full of water above the eye, and placing in the water a spoon or empty test tube. The totally reflected light gives the test tube a burnished metallic appearance.

The most common forms of **lenses** are (1) double convex, (2) plano-convex, (3) double concave, and (4) plano-concave. These are sufficiently described by section in Fig. 212. The line *A B* is the *principal axis* of each lens shown.

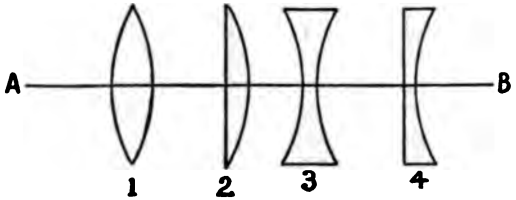


Fig. 212.

NOTE. — In this book, by convex and concave lenses will be meant spherically convex and concave. By double will be meant symmetrically double, and, unless otherwise mentioned, all lenses will be considered as immersed *in air*, and not in any other medium.

EXP. 256. — Hold a double convex lens in the direct sunshine, so that the rays of light may fall upon it parallel to the principal axis. Observe, by means of the dust, beaten from some dusty object, that

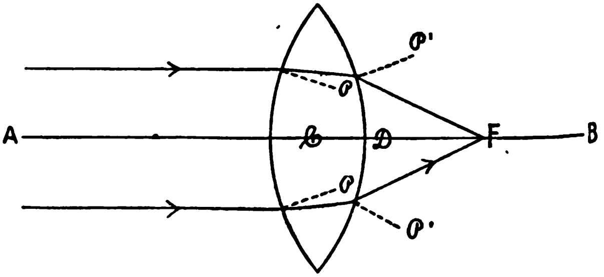


Fig. 213.

the rays are converged approximately to a point *F*, Fig. 213. This experiment is much more emphatic, if a beam of light, covering the whole side of the lens, is thrown into a dark room by the *porte lumière* (Fig. 195), and converged by the lens.

(*b*) Hold the head of a match at *F*, using the lens for a "burning glass." "Heat rays" as well as "light rays" may be refracted to a focus. [Exp. 148 and comments.]

Rays of light parallel to the principal axis of a convex lens are converged approximately to a point upon that axis on the other side of the lens called the principal focus, and, conversely, rays originating at the focus are parallel after passing through the lens.

The point *C* at the center of the lens is called the *optical center*. Any other line than the principal axis passing through *C* is called a secondary axis. Rays of light on secondary axes are not changed in direction, but suffer a slight lateral displacement like the ray in Fig. 207. In plano lenses the optical center lies at the intersection of the principal axis with the curved surface. The distance *DF* is called the *focal length*. What is the focal length of your lens? In a plano-convex or plano-concave lens, the principal axis is the normal to the plane surface which passes through the center of curvature. All "guiding perpendiculars" from the curved surface of the lens are to be drawn towards or from the center of curvature, and therefore form part of the radius of curvature, or part of this radius extended. When the index of refraction is $\frac{3}{2}$ the focal length of the double convex lens is equal to the radius of curvature, and that of the plano-convex lens is twice the radius of curvature. Construct a plot on a large scale and prove this last statement. The same is respectively true of the double concave lens and the plano-concave lens, except the foci of these are *virtual*, not real.

Exp. 257. — Slightly darken the room by drawing all the curtains but one, and draw that one half way down. Hold a double convex lens in front of the blackboard opposite this window, and obtain a small, inverted, real image.

(*b*) Fasten the lens in front of the camera, Fig. 193 (or use a regular photographer's camera), and, adjusting the screen I, by moving it nearer or farther from the lens, obtain an image of some illumined body. Fig. 214 represents object *AB* and image *B′A′*.

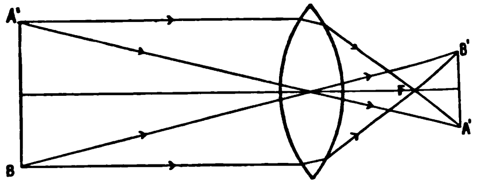


Fig. 214.

(*c*) Obtain or construct a small "magic lantern," and throw an enlarged image upon a screen (sheet, or white wall) in a dark room. Examine carefully the arrangement of lenses, or if you construct, arrange as shown in Fig. 215. The light *L* is often placed at the focus of the lens *C*. Why? The nearly transparent object *AB* becomes the enlarged, inverted image *B′A′*. *M* is a reflector placed nearer *L* than its focal length. The lens *C* is often made of two plano-convex lenses with the planes external. Why? [See Exp. 244, (*b*).]

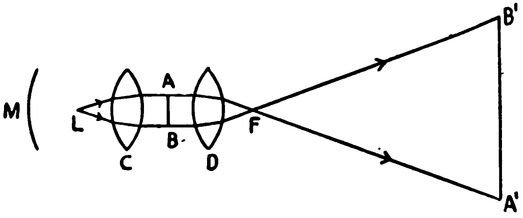


Fig. 215.

Convex lenses, like concave mirrors, have two conjugate foci, one on each side of the lens. If the object is placed in one focus a real and inverted image appears in the other focus. If the object is placed in the farther focus the lens minifies. The ordinary photographer always produces a minified image in the nearer focus, the object being in the farther. If the object is placed in the nearer focus the lens magnifies. In this case, the object, unless self-luminous, must be strongly illuminated to furnish light sufficient to make the image distinctly visible. The showman with his "lantern" always produces a magnified image of an illumined object. The lens of Fig. 214 minifies. Lens *D* of Fig. 215 magnifies. Object and image *may be* of the same size. This is the case when both are at double the focal length.

Exp. 258. — Obtain the eye of an ox from the butcher. Opposite the pupil cut away carefully with a very sharp knife the sclerotic coat, and hold the eye up to the window opposite some sunlit object. A real, inverted, and minified image appears on the retina.

The **Human Eye** is mechanically a camera. Light passing through the crystalline lens forms a real, inverted, and minified image upon the retina. In far-sightedness this retinal screen is too near the lens (conjugate focus *too far* off) for the curvature, or in other words, the lens is "too flat" for the retinal distance. In near-sightedness the retina is too far away (focus *too near*), or in other words, the lens is too convex. In each case a blurred image is formed. [See cuts of the eye in Physiologies.]

Exp. 259. — Place a small object, as an insect, upon white paper in a strong light, and examine with a double convex lens held

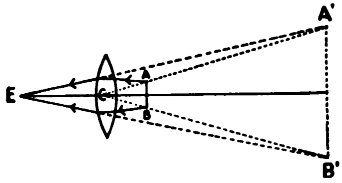


Fig. 216.

nearer to the object than the focal length of the lens. Fig. 216 explains the action of the lens. The guiding line whose intersection with the "line of sight" locates the image is drawn from the optical center *C* through *A* and *B* respectively.

Convex lenses form erect, virtual, and magnified images of objects placed nearer than the focal length. When used for this purpose they are called magnifying glasses or simple **microscopes.**

Exp. 260. — Mount a *large* double convex lens in the sunshine, and lay a graduated rod along parallel with the principal axis. With first a solid black disk of paper, covering all the lens except its edges, observe carefully the focus. Afterward with an annular piece cover the edges, leaving a portion at the center uncovered. Observe the focus. Is it nearer or farther away than before?

Spherical Aberration is caused by the fact that rays passing through the edges of the lens are brought to a focus nearer the lens than those which pass through near the center. This causes an indistinctness of outline in the image. Spherical aberration is overcome in one of two ways: —

1. By covering the edge of the lens with an opaque diaphragm.

2. By regularly lessening the curvature of the lens, that is, by giving the curved surface of the lens a continuously lengthening radius from the center outward.

Because he can get sufficient light through the center, and because it is much cheaper, the photographer usually takes the first method. The astronomer, because he needs all the light he can get, takes the second and expensive method.

Exp. 261. — Hold a double concave lens in the parallel rays of the sun reflected into the dark room by the *porte lumière*. Observe the transmitted rays. They emerge as though they came from some point *F*, Fig. 217, which is called the focus.

(*b*) Look at a small and near object through a double concave lens.

The focus of **concave lenses** is virtual, and therefore they cannot form real images. The images formed by concave lenses are always virtual, erect, and minified.

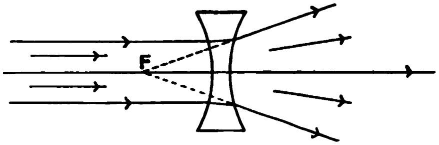


Fig. 217.

Construct the virtual image for the object *A′B′* as seen by the eye *E* through the concave lens. Use a reverse process from that shown in Fig. 216, obtaining the virtual image at *A B*.

The general effect of convex lenses is to *converge* rays, and of concave lenses to *diverge* rays. Convex lenses are very similar in effect to concave mirrors, and concave lenses to convex mirrors.

DISPERSION.

EXP. 261. — Into a room darkened as much as possible, through a long and narrow slit, introduce by the *porte lumière* a bright sunbeam. Place a prism in its path with the refracting angle downward, Fig. 218, and receive the refracted rays upon a *white* screen.

Defining with respect to sensation, **Dispersion** is the separation of light into its various colors by the action of differential refraction. The colored band produced by the refraction of sunlight is called the **Solar Spectrum.**

The rays producing the sensations of different colors have varying refrangibilities. The time-honored list from the most refrangible to the least refrangible rays, comprising white light, is: violet, indigo, blue, green, yellow, orange, red. The order may be remembered by the meaningless word, formed from the initials, *vibgyor.* For several reasons there is some overlapping of the colors.

Exp. 262. — Adjust a delicate thermometer below the red rays of the spectrum, *in the dark*, as at *H*, Fig. 218. Place a strip of "silvered" paper (obtained from some photographer, or made by dipping white paper into silver nitrate solution, and drying in the dark) above the violet in the dark, as shown at *C*. Let this paper be exposed only in spots, being covered elsewhere by black paper. The mercury rises, and the "silvered" paper above the spectrum turns much darker than at the other end.

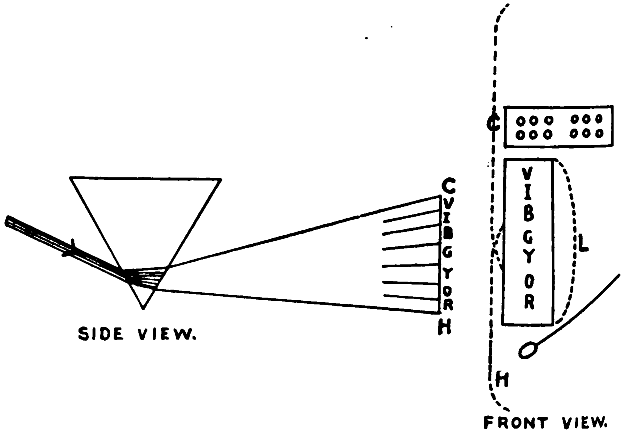


Fig. 218.

Radiant energy manifests itself in producing directly heat, light, or chemical action. Radiant energy transmitted directly from the sun produces these three effects simultaneously, by an intermingling of rays having different rapidity of segment vibrations, that is, different *wave-frequencies*. [See the first note in this chapter.] We may make three rough divisions of solar rays. Rays having comparatively high wave-frequencies do not reveal themselves to the eye as light, but are very active in producing chemical action. Such rays are refracted most. Rays having comparatively low wave-frequencies do not reveal themselves to the eye as light, but are made sensible by the heat which they produce. Such rays are refracted least. Rays of medium wave-frequency produce the sensation of light. Violet rays have a higher wave-frequency than red rays, and are therefore refracted more. [See *pitch* under Sound.]

In a loose and often very convenient sense we may say that we receive three kinds of solar rays intermingled; viz., "heat rays" (*H* dotted line, Fig. 218 front view), "light rays" (*L*), and chemical or actinic rays (*C*). The pupil will now understand that even of "light rays" there are not just *seven* kinds (or colors), but a continuous series of different degrees of refrangibility. To be strictly accurate, the index of refraction of any substance must be given for some particular ray or line of the spectrum. [Appendix, Section XII.]

Dispersion is the separation of rays of radiant energy having different wave-frequencies by means of refraction.

Exp. 263. — Look through the prism backward at the slit from a distance of two or three feet. You see a *virtual* spectrum in a direction from the slit equal to the angle of deviation for the prism (Fig. 204).

Exp. 264. — Reverse another prism, and, placing the two side by side, allow the light from a small slit to pass through both prisms. The white light separated by the first prism into colors appears again upon the screen.

(*b*) Place the prism quite near the slit, and let the beam pass through the prism and a double convex lens in such a way that the prism and the screen are at the conjugate foci of the lens. The spot upon the screen is white, at least at the center.

We may prove the composition of white light by synthesis as well as by analysis.

If we wish to obtain a *pure spectrum*, that is, one without the overlapping of rays of different refrangibility, we must place a lens in such a position as to form an accurate image of the slit upon a screen. Place the prism between the lens and screen, very near the lens, and receive the spectrum upon a second screen. at the same distance from the prism as the first. If this is carefully done, a very beautiful spectrum without overlapping of colors is obtained.

EXP. 265. — Secure the help of an assistant. Adjust very carefully a good laboratory spectroscope provided with a scale. [These cost $35 to $40.] Obtain the pure spectrum which it casts horizontally when a small electric arc light shines into the adjustable slit. Notice that the spectrum is continuous.

(*b*) Dissolve some common salt in a little water slightly acidulated with hydrochloric acid. Dip a loop of platinum wire, fused into a glass handle, into the solution, and hold it against the lower part of a Bunsen's or alcohol flame set precisely in front of the slit. The body of the spectrum is dark, but it is crossed by a brilliant yellow line (double), called the "sodium" line. Why so called?

(*c*) Carefully adjust the instrument so that the sodium line shall come precisely at 50 upon the scale. Reduce the size of the alcohol flame. Behind the flame precisely on a level with the slit, set the small arc light, so that, when it is shining, it may shine through the alcohol flame into the slit. Let your assistant cause the white light of the arc lamp to shine through the slit, while the common salt solution is being volatilized in the flame. At the same time search for the sodium line at 50. Instead of the bright line, you find a dark line precisely at 50, the rest of the spectrum being bright with the ordinary colors so far as you will probably observe.

(*d*) With a mirror throw sunlight into the slit, and observe that the spectrum is luminous for the most part, but is crossed *by dark lines*. [Appendix I., 17 and Frontispiece.]

The **spectroscope** is an instrument for studying the spectra produced by light coming from various sources.

Spectra are of three kinds: —

I. Continuous Spectra produced by light coming from incandescent (white-hot) solids, liquids, or condensed gases (vapors or volatilized material).

II. Bright line Spectra produced by incandescent rarefied gases.

III. **Absorption Spectra, like the first, except crossed by dark lines. These are produced by light of the first kind shining through substances of the second kind. Gases and vapors absorb rays of the same kind as they emit.**

The solar spectrum is of this third kind, as is also the spectra of the fixed stars. This shows that these bodies are alike in certain essential respects; viz., they have a white-hot dense interior shining out through a rarefied gaseous atmosphere, just as the white-hot particles of the electric light shone through the volatilized sodium chloride (salt). The dark lines upon the spectrum are called **Fraunhofer's lines.** They are relatively dark, not absolutely. Like the sun spots, they are dark only by contrast. If a star is approaching us, the dark lines, as shown by the scale, are all displaced slightly towards the violet end of the spectrum; and, if the star is receding, the dark lines are displaced or shifted towards the red end. An expensive spectroscope with greatly enlarged spectrum is necessary to show this well.

Exp. 266. — Volatilize, as in Exp. 265 (*b*), acidulated solutions of salts of strontium, barium, and calcium respectively. Carefully map each spectrum upon a scale, graduated precisely like the scale of your instrument.

The spectroscope is an instrument very useful to the analytical chemist, as well as to the astronomer and physicist. By it the physician may tell abnormal from normal secretions. The metallurgist and others in "the arts" find profitable use for it. [See Diffraction.]

Exp. 267. — Receive upon a double convex lens, held close to the *porte lumière* and in a dark room, a round beam of light covering half the area of the lens. Hold a piece of annealed ground glass or other similar object, first slightly nearer and then slightly farther off than its mean focus. Observe the coloration as represented with the separation of color exaggerated in Fig. 219.

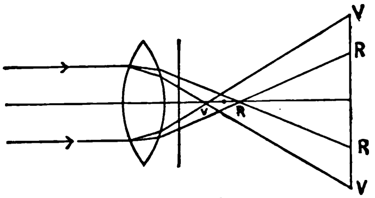


Fig. 219.

Chromatic Aberration is a defect in a lens by it brings rays of different colors to different foci.

Each color forms its own image of the object at its ow These imperfectly blended images form one blurred and image very annoying to one wishing to make careful obse For a long time this was supposed to be an irremediable lenses. It was supposed to be impossible to secure refracti out dispersion. The dispersive power of a flint-glass prism the total length of its spectrum, is about great as that of a similar crown-glass pri average refracting power, that is, the ang viation for the *center* of its spectrum, is ju the same as that of crown glass. By com double convex lens of crown glass with concave lens of flint glass, as shown in Fig. plano-concave lens neutralizes all of the d of the crown glass, and only *one-half* o fraction.

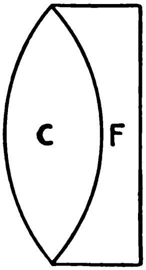


Fig. 220.

A compound lens which secures tion without dispersion is called an **matic lens.** Such lenses are used in the best tel and microscopes.

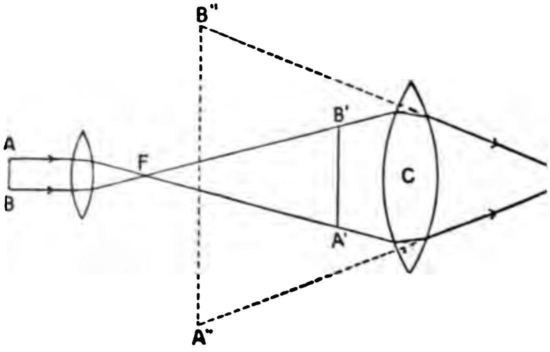


Fig. 221.

Fig. 221 shows a compound microscope. The object aced in the *nearer* conjugate focus of the object glass (objective), d the real magnified and inverted image appears in the *farther* cus at $A'\ B'$. This image is magnified by the lens C of the eye-ece, forming a virtual and erect image at $A''\ B''$, as seen by the e at E. Figs. 214 and 216 combined will help explain, in connec-on with the text, the compound microscope.

Fig. 222 shows the telescope; the object $A\ B$ being placed in the *rther* focus of the object glass, and the real minified and inverted image appearing in the *nearer* focus at $A'\ B'$. This is magnified by the eye-piece, forming a virtual image at $A''\ B''$. The object glass serves the purpose of collecting light. All the magnifying is done by the eye-piece. The microscope and telescope are very similar, as will be seen from the cuts. For the purpose of simplicity the lenses are not shown as achromatic. On terrestrial telescopes, or spy-glasses, additional lenses are used to reinvert the real image. A telescope is easily made by mounting the lenses as shown in the figure, only in a long blackened tube. The object glass should have a long focal distance, from four to six feet. [For the opera-glass, stereoscope, etc., see larger text books.]

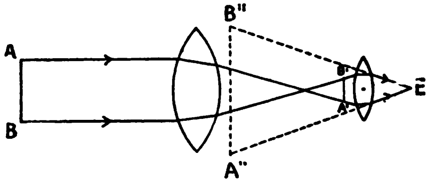


Fig. 222.

Exp. 268. — Fill a *round-bottomed* flask with clear water. Close the curtain, shutting out nearly all of the sunshine. Place against the wall, just under the window, a piece of white paper, and, holding the flask in the streak of sunshine entering beneath the curtain, observe the "rainbow" upon the paper.

The rainbow is a solar spectrum formed by drops of water. Often there are two bows. The inner, being usually brighter, is called the Primary Bow, and the outer is called the Secondary Bow.

In the Primary Bow there is one reflection (internal) only, but in the Secondary Bow there are two, as shown in Fig. 223. This

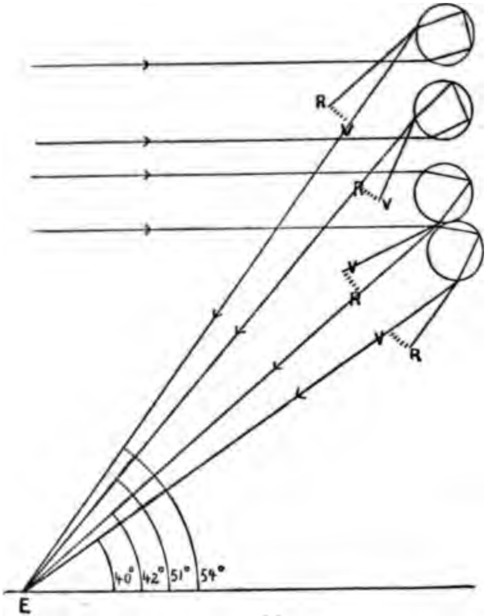


Fig. 223.

accounts for its faintness. The sun must be behind the observer, in the opposite part of the heavens from the raindrops.

COLOR.

NOTE. — Color in light is analogous to pitch in sound. [See Pitch.]

EXP. 269. — In a dark room project the solar spectrum upon a screen. Along this spectrum, in the various colors, hold bits of colored paper. Observe also the color of white and of black paper. Red is red only in the red light, etc.

The **Color** of a body does not reside in the body but given white light falling upon a body, its ıs seen by the reflected light, depends upon the ve absorption of the body. If, for instance, it ; all or nearly all of the other colors, and reflects greater proportion than any of the other colors, r will be some shade of red. If it reflects green ter proportion than the other colors, its color will ıe shade of green. If the body reflects much nd absorbs little, reflecting the colors in like pro- ıs, the "color" is white. If the body reflects ight and absorbs much, absorbing the colors in oportions, the "color" is black. Of course white ack are not strictly colors, but in a general and ense we call them such.

270. — Hold up a small piece of gold leaf, and look through ; sun. It no longer looks yellow, but has a distinctly blue

solution of fluorescene with a black paper behind it, is en; but held so that strong light shines *through* it to the ecomes a decided yellow.

es seen by transmitted light often have an en- lifferent color from that which they exhibit when reflected light.

in of the colored rays are absorbed as they pass into the e, the others emerging and giving color to the substance. rent bodies are colorless, if they absorb the colors in like ons, otherwise they have the color due to the combination of ch they transmit. Colorless transparent substances pulver- ome white, and colored transparent or semi-transparent sub- become lighter when pulverized. With the diffused light from pulverized bodies, come rays *transmitted* through the yers of the particles.

Exp. 271. — Mount a disk of "half-inch" board so that it may be whirled by means of a grooved pulley drawn by a grooved wheel. Place bright-colored paper about the marginal space as shown in Fig. 224. Place a dull white piece at the center. Whirl rapidly. The colors blend into white (or gray which is white of a low degree of luminosity).

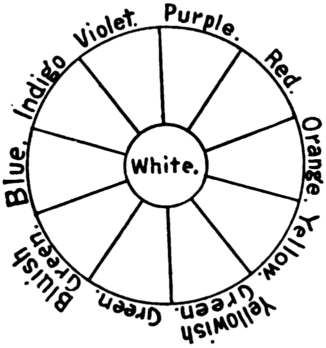


Fig. 224.

(*b*) Place red, green, and violet pieces, covering with each one-third of the margin, and whirl again. White is produced. By varying the proportion of each, any given color of the spectrum may be produced.

(*c*) Take any two colors standing opposite in Fig. 224, and covering half of the margin with each, whirl very rapidly. White results as before.

Complementary Colors are any two colors which will produce white light on mixing. Any two opposite colors in Fig. 224 are complementary. This method of "mixing colors" depends upon the well-known fact that the sensation lingers for a very short time after the cause producing it has ceased acting. [See thaumatrope, etc., in cyclopedia.] Red, green, and violet are called **Primary Colors,** because they may not only form white light, but, by varying the proportions of each, they will produce any color of the spectrum.

Two complementary colors placed near together heighten the effect by contrast, while non-complementary colors each lessen the effect produced by the other.

Exp. 272. — Place in succession highly-colored circles of paper upon a background of white paper, and, holding in a strong light, look at the circles steadily for a half-minute. Remove the colored paper quickly, and observe that the complementary color is in each case seen.

The sensitiveness of the retina for any given color rapidly decreases with the lapse of time. When white light falls upon any portion of the retina that has just been acted upon by any given color, the sensitiveness for this color having been blunted, the complement of the color is seen.

Some eyes are abnormal in this respect, that they have little or no sensitiveness for certain colors. Usually the sensation of red is lacking in such eyes. This defect is called **color blindness.** [See Dr. Thomas Young's Theory, Vision in Physiologies, and Le Conte on Sight.]

Exp. 273. — Draw a cross on the blackboard, one line with yellow halk and the other with blue chalk. Observe that at the crossing he chalk is green.

The mixture of two colored pigments often gives a ery different color from the mixture of the same colred lights.

If we mix yellow light and blue light (Fig. 224), we get white. ut a mixture of yellow pigment and blue pigment is green. In the ase of pigments the explanation lies in the differential absorbtion nd reflection of each pigment. The yellow pigment absorbing the ther colors reflects both green and yellow, the yellow overpowering he green. The blue pigment absorbing the other colors reflects both reen and blue, blue predominating. The mixture reflects green. Why?

Notes. — If through a piece of Iceland Spar a ray of light is passed by means of the *porte lumière*, two rays emerge, one stronger, the other weaker. If we look through the spar at a period, we see two periods. This action of some crystals upon light is called **Double Refraction.**

(*b*) If we take two plates of a nearly transparent mineral called tourmaline, properly cut, and, separating them by a short distance, rotate one plate parallel to and with its broad face opposite that of the other, in two positions, when the lengths of the plates are at right angles, a ray of light fails to come through the two plates; in two other positions (lengths of plates parallel) the ray readily comes through both. The ray between the plates, that is, after passing through one plate, must be in a peculiar condition different from its condition before. Such light is said to be **Polarized Light.** The vibrations in two of the four right-angled directions are supposed to have been stopped by the first plate. If the second plate is so placed as to stop the vibrations in the remaining two directions, the ray is destroyed. Light may be polarized by reflection as well as by transmission. Objects viewed by polarized light are often readily distinguished, which would be otherwise distinguished with difficulty. [See polarization in college text books.]

(*c*) Coat with India ink on one side a strip of window-glass, and, when dry, rule it finely with a needle. Looking through this glass at an illumined slit we see several spectral images of the slit. These are caused by the *interference* of the light rays. [See Interference under Sound.] We may produce a spectrum by reflecting light from a finely ruled reflector, having several thousand rulings to the inch. This formation of a spectrum by interference of light is called **Diffraction.** A spectroscope producing its spectrum in this way is called a Diffraction Spectroscope. This spectrum, however, differs in several important respects from that produced by a prism.

QUESTIONS.

1. Define radiant energy, ray, transparent, diathermanous, shadow, visual angle, real image, principal focus, conjugate foci, critical angle.

2. Explain by diagram the shape of the earth's umbra, remembering that the sun has a diameter immensely larger than that of the earth.

3. How did Roemer discover the velocity of light?

4. Two lights, *A* and *B*, equally illumine a point between them one-third of the distance from *A* to *B*. *A* is a 25-candle power light; what is the power of *B*?

5. A 5000-candle power electric light stands 2000 feet from a 16-candle power gas-jet. At what point between them do they produce equal illumination?

6.* Reflect (diagram) three incident rays from a plane mirror. (*b*) From a concave mirror. (*c*) From a convex mirror.

7. Trace a ray of light obliquely through the following, dotting he perpendiculars, and exaggerating somewhat the amount of bendng: a plano-convex lens, a double convex lens, a plano-concave ens, a prism.

8. Trace a ray of light through a double convex lens (section arge) of crown glass, fixing its directions accurately. Use $\frac{3}{2}$ as the ndex of refraction.

9. How would you find the index of refraction for coal oil?

10. Why does water "looked at obliquely" seem less deep than it eally is?

11. If a man looks obliquely into the water at a fish, does he see he fish "in the right place"? (*b*) Does the fish see the man in the ight place? Explain by diagrams.

12. Explain by diagram an instance of total reflection.

13. Explain spherical aberration. How is it corrected?

14. In what way does the image which the photographer proluces with his lens differ from that produced by the projecting lens f the "lantern"?

15. What is chromatic aberration, and how is it corrected?

16. In what three ways does radiant energy directly manifest self?

17. What are Fraunhofer's lines? (*b*) How do astronomers now that a star is moving towards us?

18. In what respects does the telescope differ from the compound icroscope?

19. Select five experiments of this chapter for which the comments exceed the proof offered by the experiment. (*b*) Select one hich proves more, or at least suggests more, than is found in the omments.

20. Suggest one experiment of your own originating, which might e substituted for one in this chapter. (*b*) Suggest one which you ave read in some other book.

21. Under what circumstances might one see a "rainbow" while prinkling the lawn? (*b*) What kind of a rainbow would it be posible to see from the summit of a high mountain?

22. Why is the secondary bow fainter than the primary?

23. In a strict sense is white or black a color? Why, or why ot?

24. What are Complementary Colors? What besides white may e produced by mixing the Primary Colors?

CHAPTER XVII.

SOUND.

NOTES. — The word sound, like the word light, is used in two very distinct senses; (1) as a cause, in which sense it is equivalent to sound-waves, and (2) as an effect or sensation. As a cause, Sound may be defined as a vibratory motion capable of affecting normally the auditory nerve. As an effect, Sound is the sensation received normally by the auditory nerve. So easily are these two meanings of the word distinguished, that writers often use the word sound in the same paragraph in both senses. (*b*) That department of physics which treats of sound when considered separately is called **Acoustics.** (*c*) With reference to Sound the word elasticity is used strictly in the sense of elastic *force*, and never in the broader and looser sense of the *property* of "returning." The "return" in volume, form, and force even, may be ever so complete, if the *force* involved in the return is small, the elasticity is small. (*d*) By the vibration of a pendulum is meant a *simple* vibration, or a single swing from one end of the arc to the other. In sound by a vibration we mean a *complete* vibration, or the motion of the particle in the time comprised between two successive passages of the particle through the same point in the same direction.

EXP. 274. — Hold a lead pencil by one end, and swing the other end through an arc at first slowly and then rapidly. (*b*) Repeat in front of the ear. (*c*) Stretch a violin string or wire taut between two screw eyes. Pluck it strongly with the fingers, and look down upon it while it is emitting sound. (*d*) Strike one prong of the tuning fork against the table, and while it is emitting sound, touch the prong to a card held against it. (*e*) Strike the fork again with considerable force against the table, and touch one prong to the surface of water. (*f*) Strike again, and look sharply edgewise at the prongs against any convenient background. (*g*) Bring the prong while sounding against the tip of the finger or tongue.

All **Sound** may be traced to some vibrating body as its source. This body, or segments of it, must be vibrating with a certain degree of rapidity in order to produce a disturbance in the conducting medium (usually air), capable of affecting the auditory nerve. Bodies emitting sound are called **sonorous bodies.**

Exp. 275. — Set one end of a brass or steel rod into a vise, and, pulling it aside, set it free. (*b*) Rosin a small piece of cloth, and, grasping the rod firmly with the cloth, give a quick rubbing stroke downward. Listen for any sounds which it may emit. (*c*) Suspend the rod from a vise, and upon the lower end clamp a heavy stick. Twist and set free.

Vibrations in solids may be transverse, longitudinal, or torsional. They may be rapid enough to produce the harmonic motion called sound (sound-waves), or slow enough to fall to the grade of harmonic motion represented by the pendulum.

Exp. 276. — Pluck a stretched string or wire gently, observing the width or amplitude of the vibration, and the loudness of the sound. Pluck again vigorously, and observe as before. (*b*) Divide one sheet of paper so as to take one-half and one-quarter of it. Grasp by one side, and shake successively the quarter-sheet, the half-sheet, and the whole sheet, causing each to "crackle." Observe which produces the loudest sound. (*c*) Hold a watch to the ear, and observe how rapidly the sound decreases in loudness as it is removed.

The mechanical **intensity** of sound varies as the square of the amplitude of vibration of the sonorous body, approximately as the area of the vibrating surface in contact with the conducting medium, and inversely as the square of the distance from the sonorous body. The intensity of sound is greater if the density of the gaseous medium surrounding the sonorous body is greater. One must speak "softly" in a diving-bell, and "louder" upon the mountain-top. Loudness of sound, or the sensation effect, shows only very roughly the intensity.

Exp. 277. — Prepare a framework about 15 dcm. long and 8 dcm. high, Fig. 225. Prepare three dozen lead bullets about 1 cm. in diameter by driving double-pointed tacks into them and preparing very short S-shaped hooks to hang them on. Suspend each by a double thread falling from screw-eyes, so that the distance *A* is 2 cm., and the distance *B* 1 cm. Tie the adjacent threads, suspending adjacent balls by horizontal loops *a*, *b*, etc. (rendered loose by tying into each a knitting-needle, and afterward withdrawing the needle). Slip these loops down *evenly*; the nearer they are to the balls the greater the *force* which resists any disturbance of the balls. This force corresponds closely to elasticity, the balls representing molecules. With two very slender elastics, *E É*, tie back each side to rods upon which the elastics slide, till the pendulum *P* hangs at the center of the first tied loop on the right. By means of extra screw-eyes, shown on the front of the top part of the frame, adjust the balls till they are precisely level. Below place a hinged strip of board about 1 dcm. wide for a "damper," which may be raised to stop the balls. A narrow, movable, straight-edged strip of board resting on supports at two different heights, the second about 4 cm. above the first, will assist in keeping the loops level in two different positions. Take hold of the first right-hand loop and suddenly swing it out and back once at right angles to the line joining the balls. A disturbance similar to the water wave passes from the right to the left through the apparatus. Notice that each ball moves roughly at right angles to the line of progression of the disturbance, with a slight rotary motion.

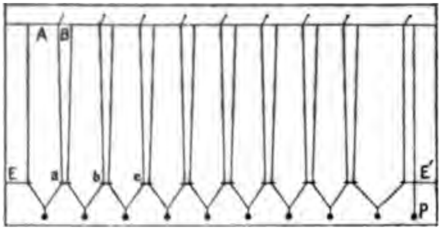


Fig. 225.[1]

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[1] Modified from apparatus in Stanford University physical laboratory.

Stop the motion with the damper, and repeat, studying the motion which represents in most essentials the water wave.

(*b*) Take hold of the first loop on the right and give it a quick motion to the left, and back again. Watch the progression of the disturbance through the apparatus. Remembering that the balls represent molecules, and the *force* with which the loops hold them in position represents elasticity, repeat. Time by counting the ticks of a watch while the disturbance is passing. Take no note of the tremulous disturbance passing in advance over the strings, but time the disturbance as it passes through the ball, till a quick backward movement takes place in the ball next to the end ball on the left. This indicates that the disturbance has crossed, and has just started to return. Set down the number of "ticks" to compare with (*c*) and (*d*). .

(*c*) Raise the loops to the second position, as shown by the guiding strip of board. This decreases the *force* (elasticity) with which the balls resist a disturbance. Repeat (*b*), timing as before. The disturbance progresses much more slowly, as shown by the number of "ticks." [Loops and elastics should be at the same level.]

(*d*) Bring the loops to the lower level as at first. Unhook the lead balls, and hang in place of each as removed a light glass bead of the same size. This may be prepared by plugging with cork, and inserting a hook made of fine copper wire to hang from the S-shaped hooks. This changes the density of the material through which the disturbance is to pass. Press the loops still farther down till the strain upon them (elasticity) as shown by the elastics is about as in (*b*). Repeat (*b*).

The **water-wave** travels by a series of *crests* and *troughs*. **Sound-waves** travel by a series of *condensations* and *rarefactions*. The molecules of the water over which the wave is passing vibrate roughly at right angles to the line of progression of the wave. The molecules of a substance, solid, liquid, or gas, through which a sound-wave is passing, vibrate parallel to the line of progression of the wave.

Other conditions remaining the same, Sound travels more rapidly as the medium through which it travels becomes more elastic or less dense. Physicists have demonstrated that the velocity of the sound varies *as the square root of the elasticity* and *inversely as the square root of the density* of the transmitting medium.

In Fig. 226 is represented graphically the action upon the molecules of the air (or other medium), as a sound-wave passes out from the sonorous body *S*. The vibrating body strikes the air, producing a condensation, and then immediately rebounds, producing a rarefaction. The closer parallel curves show the condensation, and the parallel curves farther apart the rarefaction. The law of intensity is easily seen from the cut. The *surface* layer only of the sphere strikes the drum of the ear *E*, and the surface of spheres are to each other as the squares of their radii. "Speaking-tubes" prevent the wave from expanding, and therefore the energy involved, being exerted in the forward direction only, propagates the disturbance with much less loss of intensity. A stick of timber or rod of metal operates like a speaking-tube, a scratch or blow upon it at one end being heard very distinctly at the other end.

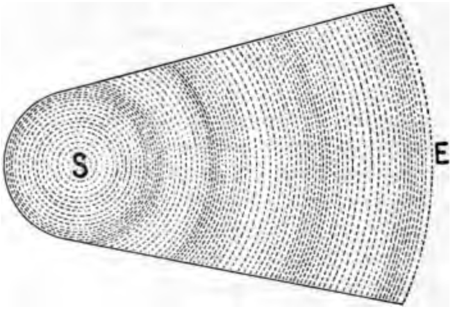

Fig. 226.

Exp. 278. — Find the velocity of sound in air. Prepare a seconds' pendulum. On some morning when there is no perceptible wind, take a station with hammer and an "anvil" of some sort. Attach to the hammer a white object, as a large card, and secure a proper background, that an assistant at a distance may observe, as well as hear, the blows. Strike the anvil regularly as the pendulum completes its stroke. Let the assistant go farther and farther away till he hears any single blow just as the next blow is struck. Measure the distance in feet. If this experiment be performed in the cool air of a frosty morning, and in the heated air of the early afternoon, it will be found that the assistant stands a little nearer in the afternoon. Care must be taken that the wind does not interfere with the experiment. The passage of light over so short a distance is practically instantaneous.

The velocity of sound in air at 0° C. is 1,090 feet per second; and this velocity increases by about one foot for each Fahrenheit degree, or about 1.8 feet for each centigrade degree. At ordinary comfortable temperatures, therefore, the velocity of sound in air is about 1,120 feet per second. Variation in the barometer does not affect the velocity, as according to Mariotte's Law the elasticity (E) increases or decreases in the same proportion as the density (D), when pressure is increased or decreased, and V being equal to $\sqrt{\frac{E}{D}}$, the quotient V remains the same, whatever the height of the barometer.

The velocity of sound in water is about 4,700 feet per second, in iron about 16,820 feet. Although the density of each of these is vastly greater than that of air, and so far as the factor of density goes, the velocity should be less, yet the elasticity is greater than that of air *in far greater* proportion. [For finding the velocity of sound in glass, brass, iron, etc., see laboratory manuals and college text books.]

Exp. 279. — Arrange two pendulums to vibrate in the same time. Hang from the same frame one shorter and one longer pendulum. Set one of the two equal pendulums vibrating in a long arc. Which of the three remaining pendulums is most disturbed by the vibration? The greater vibration in this one is called a *sympathetic*

vibration, and the lesser vibrations in the two others are called *forced* vibrations.

(*b*) Sound the tuning-fork and touch the handle to a dry board (sounding-board), or to the top of the table. Vibrations are *forced* in the board, being communicated through the handle.

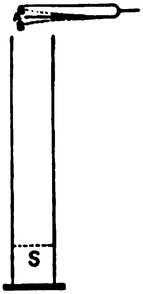

Fig. 227.

(*c*) Raise the damper from the strings of the piano, and sound slowly several notes successively close by the instrument. Listen each time for a response. When you give the same tone as any given string gives, there is a loud, *sympathetic* response from the string.

(*d*) Sound a tuning-fork above a resonance tube, Fig. 227, pouring in water gradually till a loud sound is produced by the resounding of the tube of air.

(*e*) Observe on some picnic how much more difficult it is to hear a speaker in the open air than to hear one in a closed room.

Re-enforcement of sound is usually secured: —

1. By Forced Vibrations in solids.
2. By Sympathetic Vibrations in solids, or in partially closed columns of air. In this latter case the re-enforcement is called Resonance.
3. By Reflection.

A reflected sound-wave is shown at various stages of progress in Fig. 228; the advancing wave in dotted lines, and the reflected wave by continuous lines. Just as the eye cannot distinguish *two* similar flashes of light, if they occur within a minute fraction of a second of each other, but considers the flashes *one*; so the ear cannot distinguish a sound from its reflection, if the reflected sound reaches the ear within a sufficiently short interval after the direct sound. This interval varies slightly, as we would suppose, for different persons, being, however, in all cases, some small frac-

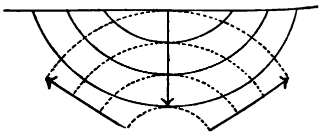

Fig. 228.

n of a second. When the reflecting surface, like the walls of an dinary room, is sufficiently near, the reflected sound blends with e direct, and thus re-enforces the original sound. If the reflecting rface is so far away that the reflected sound is distinguished by the r from the direct sound, an **echo** is produced. An echo, then, is sound that comes by reflection, too late to re-enforce the original und. Multiple echoes are produced by parallel walls far apart, as e abrupt shores of the celebrated "echo lakes," or by reflections e after the other from separate reflecting surfaces. In large sembly halls the echoing is largely overcome by breaking up the flecting walls by woodwork, drapery, etc. The "resounding" and reverberating" of the hills is caused by the resonance of the parally confined air of the canyons or valleys, and also because of the ultiple reflections from hills to hills, hills to clouds, clouds to ills, etc.

Exp. 280. — Mount two mirrors, *M* and *M'*, Fig. 229, about 8 dcm. art, and accurately facing each her. Suspend a watch at the cus *F* of one, and hold a piece rubber hose, one end to the r *E*, and the other end facing e mirror *M* at the focus *F'*. he watch is heard ticking very stinctly if the experiment is refully performed. Regularly rved tins prepared by a tinith will answer for mirrors. e front of the advancing sound-ve lies in a convex surface (Fig. 226), between the watch and the st mirror. Between the two mirrors it lies in a plane surface; and tween the second mirror and the end of the rubber tube the front rms a concave curve, converging its energy to the focus. [Fig. 228.]

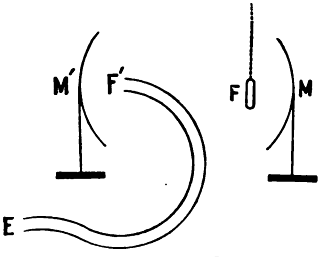

Fig. 229.

(*b*) Fill a toy balloon with carbon-dioxide, and, using this for a uble convex lens, hang a watch on one side of it, and, placing the r on the other side, find a point where the ticking is heard more stinctly than elsewhere.

(*c*) A hot ball at *F* will cause a thermometer at *F'* to "rise" gher than a thermometer at an equal distance at the side. [Exp. 8 and comments.]

Sound, as well as radiant energy, may by reflected to a focus by a mirror, and refracted to a focus by a lens.

"Whispering galleries" are constructed on the principle shown in Fig. 229. If the reflectors were large, and were properly made and adjusted, a person at *F*, speaking very low, might be heard distinctly by a person at *F′*, and *vice versâ*, across a large assembly-hall from gallery to gallery. Sound cannot be advantageously refracted by a lens, because most of the energy involved is lost by reflection. [See "ear of Dionysius," speaking-trumpets, ear-trumpets, etc., in cyclopedia.]

EXP. 281. — To measure the wave-length. This is the distance between the center of one condensation and that of the next condensation in the transmitting medium. [See Fig. 225.] It is the distance traversed by the wave during one vibration period of the sounding body. This must not be confounded, as is often done by beginners, with the *amplitude of vibration* of the sonorous body, *B* to *C*, Fig. 227. Over a resonance tube about 4 cm. in diameter, Fig. 227, sound a tuning-fork, and adjust carefully the length of the air column *B S* by drawing out or pouring in water, with a pipette. When the loudest resonance is obtained, measure the distance *A S*. This is approximately *one-fourth of the wave-length*. The condensation must pass down to the surface *S*, and be reflected so as to join the upward motion of the fork at *A*. The wave passes from *A* to *S* and returns while the prong is making one-half of a vibration.

(*b*) Use a tuning-fork of higher pitch, and observe that the resonance column must be shortened ; or of lower pitch, and notice that the column must be lengthened.

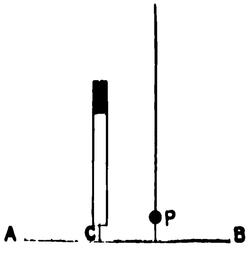

Fig. 230.

(*c*) To find the vibration-number of a tuning-fork, that is, the "vibration-frequency," or the number of vibrations per second. Attach with a *little* wax a fine bristle, *C*, Fig. 230, to one prong of a tuning-fork, and also one to the lead bob of a short pendulum *P*, beside which the fork is firmly suspended. Time the pendulum accurately, finding by counting for one minute the fraction of a second required for a *single* vibration. Prepare a long and narrow piece of glass, *A B*, by covering with fine flour sprinkled from a tin box, over whose mouth a paper perforated with fine pin-holes has been tied. Place the glass beneath, and adjust so that the two bristles just touch the glass. Swing the pendulum, and strike the fork with a small wooden hammer. Push the piece of glass along with a steady movement till it passes beyond both bristles. Count the sinuosities produced by the fork between any two strokes of the pendulum, remembering that we mean by a vibration of a sonorous body a *complete* vibration. Compute the number of vibrations per second.

The **wave-lengths** in air may be found approximately by multiplying the length of the air column giving the best re-enforcement, by four. Vibration-number, wave-length, and velocity are manifestly related as shown by the equation —

$$\mathbf{W} = \frac{\mathbf{V}}{\mathbf{N}}$$

in which W is the wave-length, V the velocity, and N the vibration-number. Any two, therefore, of these being given, we may find the third.

Exp. 282. — Cover the plate of the air-pump deep with soft wool (or cotton), and upon the wool set a small alarm clock, which you set to "go off" as soon as the air is exhausted. The sound is very faint.

Sound cannot pass through inelastic media. Sound cannot travel in a "vacuum." No sounds can reach us from the sun, though *at* the sun the explosions are terrific beyond comparison with anything which the earth can produce. No vibratory motion could travel in an absolute vacuum; and as light is a vibratory motion, and comes to us from the sun, the "vacuum" between us and the sun cannot be absolute. Ether fills this "vacuum," but sound cannot travel through ether.

Exp. 283. — Drop two bullets into a tub of still water, and, with properly adjusted light, watch carefully the enlarging waves as they meet. Along certain lines where the crest of the wave produced by one bullet meets the trough of the other wave, the water is level.

(b) Sound the tuning-fork, and rotate it upon its longitudinal axis in front of the ear, or above the resonance tube of Fig. 227. Along the diagonals the condensation produced by one prong of the fork meets the rarefaction produced by the other prong. The two sound-waves along these lines interfere and destroy each other so that no sound is heard.

Water-waves are destroyed by interference when the crest of one wave meets the trough of a like wave. Sound-waves are destroyed by **interference** when the condensation of one wave meets the rarefaction of a like wave. A study of Fig. 226 will make clearer the phenomenon of interference.

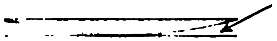

Fig. 231.

That light is propagated by a vibratory motion is considered proven by the fact that we may easily produce *interference of light* by placing a plano-convex lens of long focal distance upon a level plate, and introducing a colored ray, for instance, yellow, as shown in Fig. 231. Alternate circles of light and darkness appear, because of the meeting by reflection of the vibratory motion in unlike phases. If white light is used, the interference produces prismatic colors. These colors are easily produced by pressing together very firmly two pieces of glass in a strong light. [See Note at the beginning of Chapter XVI., and Diffraction.]

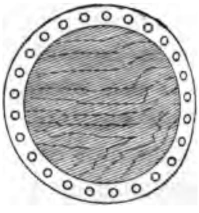

Fig. 232.

Exp. 284. — Mount upon a smaller circle of wood a stout circular card 3 dcm. in diameter, through which, about the edge, holes 2 cm. apart and 5 mm. in diameter have been cut by a "cork-borer." Clamp a glass tube of cross section equal to that of one of the holes, and half closed by melting at the end, so that the tube points horizontally at any hole, just clearing the disk. Connect a rubber tube to the other

end, through which to blow. Turn the mounted disk, increasing the speed while blowing through the holes. Observe the rise in pitch after the puffs have increased in frequency sufficient to produce a musical tone.

(*b*) Turn a given number of times per minute, and then double the number of times, timing the turns by two pendulums. Notice that the difference in pitch is an octave.

Pitch depends upon the rapidity of the vibrations. If the vibrations per second are greater, the pitch is higher. Such an apparatus as is shown in Fig. 232 is called a **siren.** Mechanism for revolving the disk steadily and for automatically counting the revolutions is attached. The tone of the siren is brought into unison with the tone whose vibration-frequency is to be measured, and the disk is then revolved for one minute. A simple multiplication of the revolutions into the number of holes, and this product by 60, gives the pulses, or vibrations per second. An **octave** is produced by double the number of vibrations, or by one-half the number of vibrations which produce the given tone from which the octave is measured.

Exp. 285. — To a dry sounding-board fasten two heavy blocks of wood, *C*, *E*, Fig. 233, a little longer than the board is wide, that they may be screwed to the table conveniently. Fasten two triangular strips, *A* and *B*, to the board, three feet apart from apex to apex. With a spring balance at *D*, stretch a spring brass wire (No. 22) between the tension pegs *G* and *F*, till the balance shows a tension of from six to eight pounds. The apparatus is called a sonometer. Using a square, and measuring along the string *from B*, but working from *A* towards *B*, mark off upon the sounding-board below $\frac{8}{9}$, $\frac{4}{5}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{3}{5}$, $\frac{8}{15}$, and $\frac{1}{2}$ of the string. Pluck the string with the right hand,

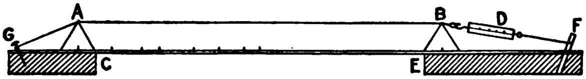

Fig. 233.

near *B*, observing its tone as the whole vibrates. With the left hand grasp the string near *A*, leaving $\frac{8}{9}$ of it free to vibrate, and sound again. Repeat successively, leaving $\frac{4}{5}$, $\frac{3}{4}$, etc., free. The eight notes of the Gamut or Diatonic Scale are heard.

(*b*) Stretch two precisely similar wires side by side, and place upon the second a tension four times as great as upon the first. Adjust carefully, jarring the apparatus so that friction may be ruled out as much as possible. Run through the octave again upon the first, and immediately sound the second. It should be in unison with the note given by one-half the first.

(*c*) Stretch two wires of the same material, but one having twice the diameter of the other (Nos. 22 and 16 about). Place equal tension upon each, and, running through the octave upon the heavier, immediately sound the lighter string. Half the first should be in unison with the whole of the second.

Law of Strings. The vibration-numbers of strings of the same material vary *inversely as the lengths, directly as the square root of the tensions, and inversely as the diameters.*

To raise the pitch of a string one octave we may reduce its length *one half*, or we may make the tension four times as great, or we may reduce its diameter one-half, in each case leaving the other conditions the same. To lower the string one octave we may double the length of the string, or reduce the tension to one-fourth of the original tension, or make the diameter twice as great, other conditions in each case remaining the same.

Taking the vibration number of middle *C* as 256, as is usually done by physicists, we have for the Diatonic Scale: —

Vibration-number	256	288	320	$341\frac{1}{3}$	384	$426\frac{2}{3}$	480	512
Letter	C	D	E	F	G	A	B	C
Syllable	Do	Re	Mi	Fa	Sol	La	Si	Do
Vibration ratio	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2

In German instruments the vibration-number of C is taken as 264. Often in this country 261 is taken. The so-called "concert-pitch" assigns about 269 to C. These assignments of course vary the other numbers of the scale, the vibration-ratio remaining the same in all cases. As the table shows, the intervals are by no means equal. Into the longer intervals of the scale in the process of equal "tempering" are introduced five additional notes, called "sharps" of the note below or "flats" of the note above. The original eight notes are also slightly adjusted as to their vibration-numbers. This scale is called the Chromatic Scale. The five black keys of each octave of the piano represent the interpolated notes.

Exp. 286. — Upon the string *AB*, Fig. 234, hang riders (narrow strips of paper bent at the middle) at *R*, *N′*, and *R′*, *N′* being one-third of the way along the string from *A* towards *B*. Touch the string at *N* one-third of the way from *B* with the "rubber end" of a pencil, and pluck the string gently a number of times near *B*, increasing gradually the disturbance till the riders *R* and *R′* jump off. The two points, *N* and *N′*, which are comparatively at rest, are called *nodes*, and *R* and *R′*, the points having the greatest energy of vibration, are called antinodes.

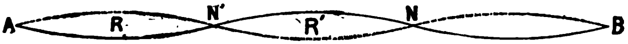

Fig. 234.

(*b*) Divide the string similarly into four vibrating segments, obtaining three nodes as shown by attaching additional riders.

(*c*) Pluck the string *at the center*, and listen for a strong lower tone, and as the sound dies away for less intense tones of higher pitch.

The tone produced by a string vibrating as a whole is called the **Fundamental Tone.** The tone produced by any vibrating segment of the string is called an **Overtone.** It is impossible to produce the fundamental tone without at the same time producing overtones. By skill in applying the disturbing force we may enfeeble the fundamental tone and strengthen the overtones, or *vice versa.* This may be done without damping the string and forcing a node, as in the experiment. If the vibration-number of an overtone is a small multiple of that of the fundamental tone or of another overtone, as two times, three times, four times, etc., the tones blend pleasantly, and the higher tones are called with reference to the lower **Harmonics.** If a performer exercises skill in applying the disturbance so as to enfeeble the fundamental tone and strengthen the "blending" overtones of his instrument, he is said to be playing "in harmonics."

When three notes whose vibration-numbers are as 4:5:6 (C, E, G, or do, mi, sol) are sounded together, the harmonic combination is called a *major triad*; and if four notes whose vibration-numbers are 4:5:6:8 (C, E, G, C', or do, mi, sol, do) are sounded together a *major chord* is produced. [See minor chord and harmony in larger works.]

EXP. 287. Bore a hole through the center of a thin piece of glass, Fig. 288, about one foot square, and mount upon a block of hard wood by means of a long screw. Put a lead washer below the glass and a lead and a brass or copper washer above. See that the surface is perfectly level. From a tin can covered with a stout paper perforated in many places by pin holes sprinkle fine sand upon the plate. Forcing a node by touching the plate with a pencil at a point about half way from the margin towards the center, set the plate in vibration with an old violin bow. Observe the nodal lines and roughly the pitch of the tones.

FIG. 288.

(*b*) Brush off the sand, and cover again as before. Force a node at a different point, and observe the nodal lines. Is the pitch higher or lower? Are the vibrating segments larger or smaller than before? [See Chladni's Figures in larger works.]

The fundamental tone of a plate or bell is given when it vibrates in four segments. The smaller the vibrating segments the higher the pitch of the overtones. Many of the overtones of the plate are not harmonics. All of the intense overtones of a fine-toned "chiming-bell" are harmonics.

Sounds of excessively high pitch, and therefore overtones of the same pitch, are disagreeable to the ear, especially if the intensity is great. For example, the sound when a stick of chalk is drawn against the board at an angle of nearly 90° is at once protested against by every one present. Sounds of extremely high or of extremely low pitch (vibration-frequency great or small) become inaudible, just as rays of radiant energy of extremely high vibration-frequency (above the violet), or rays of extremely low vibration-frequency (below the red), become invisible. Indeed, color in light corresponds precisely to pitch in sound, the violet corresponding to high pitch, and red to low pitch. Different ears vary, as we would suppose, in their appreciation of pitch. It is not a very uncommon thing to find a man who cannot "hear the cricket" because of the extremely high pitch of the sound, nor again to find a man who cannot hear the rumble of distant thunder because of the exceedingly low pitch.

Exp. 288. — Make a wind instrument about 8 dcm. long of thin dry wood. Let the cross section inside be about 4 × 4 cm. Prepare a plug *P*, Fig. 236, covered with soft leather, carefully fitting the tube of the instrument and attached firmly to a handle. Sound the closed pipe, blowing with just sufficient force to produce a clear tone. Open the pipe, and sound again a clear tone. Observe the difference in pitch.

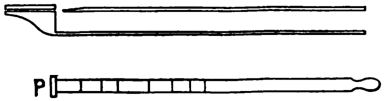

Fig. 236.

(*b*) Tune the string of Fig. 233 so that its fundamental tone is in unison with the wind instrument when the plug is inserted a short distance. Rule a line on the handle guided by the end of the tube. Call these unison notes the key-note, or *Do*. Sound Re on the string and push in the plug till the tones are again in unison. Mark again upon the handle the distance. Repeat till all the notes of the octave are sounded. Remove the plug, and observe the intervals as marked upon the handle. Compare the relative sizes of the intervals with those upon the sounding-board beneath the string.

(*c*) Without changing the plug, blow gently and then somewhat violently, observing the difference in pitch.

Wind Instruments are instruments inclosing more or less completely columns of air. These columns are thrown into vibration by pulses of air thrown across an opening at one end, or by the vibration of *reeds* at one end. An open pipe gives as its fundamental a tone one octave higher than a closed pipe of the same length, or the same tone as a closed pipe of one-half its length. In both closed and open pipes the vibration-number is inversely proportional to the length of the pipe, the law being the same as for strings. To produce tones of the best quality, however, the cross section must increase with the length of the pipe.

The fundamental note of a closed pipe is produced with a node at the closed end, while that of an open pipe is produced with a node at the center end and antinode at each end. This may be shown by lowering a thin disk carrying fine sand down into the pipe while it is sounding its fundamental note. In instruments of which the fife is a type, the column of air is shortened by opening holes from one end towards the other. The notes of the second octave in the fife are produced by skillfully blowing so as to set the air column vibrating in shorter segments; that is, the second octave is played "in harmonics."

Exp. 280. — Sound the string of Fig. 233 vigorously, and lessen the tension while it is sounding. A discordant, "groan-like" sound is heard.

(*b*) Strike two adjacent keys of the piano and hold them down, listening to the varying intensity of the resultant sound, or

(*c*) Attach a piece of wax to one prong of the tuning-fork. This will retard the motion of this prong. Sound the fork upon a soundng-board.

Beats are heard when two sounds are produced havng their vibration-numbers different by a small but distinctly perceptible amount. The two condensations at first coming together cause an outburst of sound, and then the condensation produced by one meets the rarefaction produced by the other, causing a great weakening of the sound. Beats are characteristic of discordant sounds, and they are produced by a species of interference.

The action is precisely similar to that of two water waves of different wave lengths, and consequently of different wave-frequencies (vibration-numbers), advancing over the same surface. Part of the time the two waves would meet in like phases and the two crests would make a higher wave, and part of the time the two waves would meet in unlike phases and the crest of the smaller would partly fill the trough of the larger.

One sound can differ from another sound only in three respects: —

1. In Intensity.
2. In Pitch.
3. In Quality.

The intensity and pitch of the fundamental tone being the same, the **Quality** of any sound depends upon the number, kind, and relative intensity of the overtones present.

For instance, if a flute and a fife should sound one after the other a tone of the same fundamental pitch and intensity, the two notes could be instantly distinguished by the quality of the sound. We

usually distinguish voices as well as instruments by their quality. If the pitch of a person's voice is exceptionally high or low, we sometimes recognize the voice by the pitch.

Helmholtz proved by very interesting experiments the nature of quality in sound, and showed, for instance, that the notes of the flute are far "richer in harmonics" than those of the fife. By means of a series of metallic resonators, Fig. 237, from large to small, we may analyze sound waves. The end *E* is placed at the ear, and the sound wave enters at *S*, causing the resonator to resound with a sympathetic vibration whenever the overtone in unison with the fundamental tone of the resonator is present in any note. Such resonators are called **Helmholtz's Resonators.** The "resounding" of shells placed to the ear is caused both by true resonance, and by multiple reflections of sounds inaudible to the unaided ear.

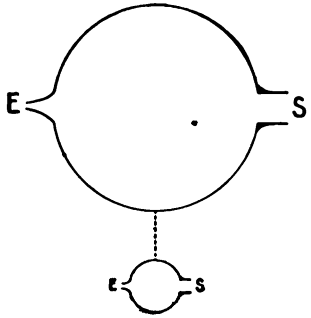

Fig. 237.

Exp. 290. — Place the fingers upon the larynx, and sound first a high note and then a low one. The larynx is first raised and then depressed. Why?

(*b*) Examine the vocal cords from some animal (cat, dog, or sheep) after the "false vocal cords" above have been cut away. The tendon-like chords (conventionalized as *AB* and *CD* in Fig. 238) have membraneous attachments (shown by the ruled lines) covering on each side the orifice opening upward from the larynx. The central opening is called the glottis.

(*c*) Examine the middle and internal ear in some animal, and also cuts of the human ear in some physiology.

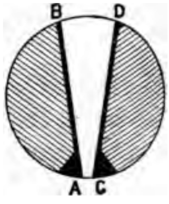

Fig. 238.

The **Vocal Chords** situated at the top of the larynx are the essential organs of the voice, the pharynx and mouth operating as a resonance tube. By muscular action these chords may be placed under greater or less tension. In different individuals they may be longer or shorter, "heavier or lighter," or stretched with greater or less force. Cultivation of the voice in music consists principally in improving its quality, that is, in acquiring skill to produce from the vocal chords more numerous and more agreeable overtones to blend with the fundamental tone. Mechanically the vocal apparatus is a *reed instrument*, and the middle ear is a *drum*. The receiving membrane of this drum vibrates with sympathetic or forced vibrations, and communicates these vibrations to a second membrane. Between these two membranes the drum has a vent to the pharynx through the Eustachian tube.

Exp. 291. — Fasten a linen thread to the bottom of two tin cans, or connect them by a fine wire, Fig. 239. The thread or wire *C* transmits readily the sound wave entering *A*, reproducing similar sound waves in the air at *B*.

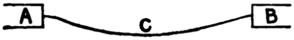

Fig. 239.

In the "**acoustic telephone**" sound is transmitted over the wire or connecting thread by the ordinary series of condensations and rarefactions.

Exp. 292. — Make the delicate galvanoscope more delicate by placing the north-seeking pole of a bar magnet north of the needle, and bringing it "end on" as near the needle as possible without causing it to swing. This weakens the earth's force lines by producing force lines in the opposite direction. Wind about a round bar magnet at one end several hundred turns of fine copper wire, and at a distance of at least one meter attach the galvanometer *G*, Fig. 240, covering it with a glass case to prevent drafts of air. Bring a piece of soft iron *A* suddenly against the magnet. The needle should turn very slightly. The force lines are drawn forward to the soft iron and thus more of them *thread the coil*, giving an induced anti-clockwise current. Withdraw suddenly the armature *A*, a current passes in the opposite direction.

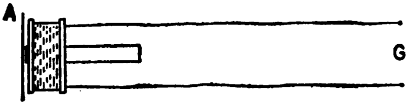

Fig. 240.

(*b*) Prepare two thin sheets of tin-type iron (diaphragm), *A* and

B, Fig. 241, and set them very near and in front of two fixed bar magnets after winding the magnets as before. Connect the wires so that an anti-clockwise current (looking in the direction of the force lines running through the magnet) about

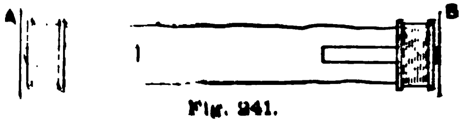

Fig. 241.

the magnet at *A* shall pass around the magnet at *B* anti-clockwise strengthening the pole at *B*. Let the soft iron diaphragm rest upon wooden supports so that though very near they shall not touch the magnets. Let some one strike very gently with a pencil the diaphragm *A*, while you listen with the ear near *B*.

(c) Examine the receiver of the Bell Telephone, Fig. 242.

The **Bell Telephone** is an apparatus for producing secondary sound waves in the air at a distance from the primary sound waves by means of electricity. The sound does not pass over the wire, but an induced current passes. This current is an effect with respect to the speaking end, and a cause with respect to the hearing end.

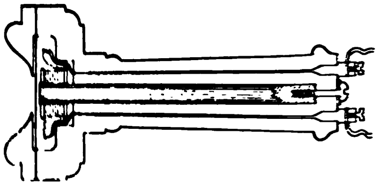

Fig. 242.

The processes of telephoning may be stated as follows:—

1. The vocal chords of the speaker vibrate.
2. This vibration produces sound waves in the air.
3. These sound waves striking the diaphragm cause it to vibrate.
4. As the diaphragm swings nearer the magnet more force lines are drawn forward through the coil to return to the south-seeking pole through the soft iron, instead of passing outward through the side of the coil [see Fig. 140]. As the diaphragm swings farther

away less force lines thread the coil, more passing out at the side.

5. Increasing force lines threading the coil produce an anti-clockwise induced current, and decreasing force-lines produce a clockwise current.

6. This induced current passes around the magnet at the receiving end first to strengthen the magnetism by *adding* its force lines to those of the magnet, and second, to weaken the magnetism by *subtracting* its force lines from those of the magnet (by sending them in the opposite direction).

7. This increasing and decreasing of the magnetism at the hearing end draws forward and releases the diaphragm so that it vibrates, if the apparatus is perfect, just like the diaphragm at the speaking end.

8. The like vibrations of the second diaphragm produce as an effect sound waves in the air like the causal air sound waves at the speaking end.

9. These sound waves strike the outer membrane of the ear of the listener, and are heard as the primary air sound waves would be heard.

Soon after the invention of the telephone, it was found that it was better to use a different instrument at the speaking end, especially for *long distance* work. Indeed, the simple Bell telephone, as represented above, because of the exceeding weakness of the induced current, will work only on short distances. This instrument is called a **Transmitter,** and its operation *involves the use of a battery* or other "generator." Its principle is that of the **Microphone** [which see in larger text-books]. Variation in the pressure with which two carbon terminals behind the diaphragm are held together causes the resistance to vary greatly. For this reason the current will vary greatly and in proportion.

The **Blake Transmitter** with connections is shown in Fig. 243. The current from the battery F passes through a primary coil between P and P' to the insulated spring E through the carbon terminals C, from the heavier spring E' back to the battery F. A secondary current SS' passes over the line wire to a station in which the apparatus is duplicated; but the hearer places his ear to the Bell receiver corresponding to R. As the diaphragm D vibrates, the varying pressure gives a varying primary current and consequently a varying secondary. This varying secondary produces vibrations in the receiving diaphragm.

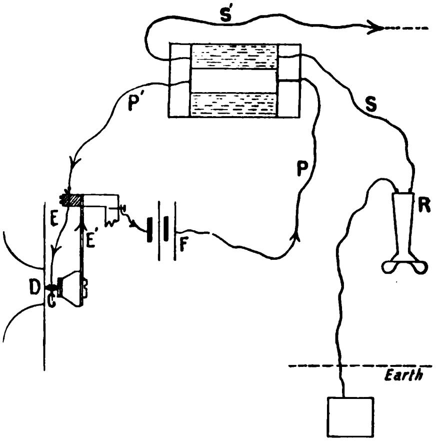

Fig. 243.

The **Phonograph** is an instrument for recording and reproducing sound waves. The principle upon which it acts is very simple. Fig. 244 represents the vibrating diaphragm D, the attached "style" S, and a portion, CC', of the wax covering the hollow cylinder upon which the style makes indentations, whenever sound waves strike the diaphragm. The cylinder is steadily revolved with a progressive forward motion, causing the style to trace the indentations in an open curve from one end of the cylinder towards the other. Whenever the sound is to be reproduced, the style and cylinder are brought into the same relative position as at the beginning, and the cylinder is again revolved. The style rising and falling as it passes along the curve of indentations causes the diaphragm to vibrate as before. This produces secondary sound waves in the air like the causal and primary waves.

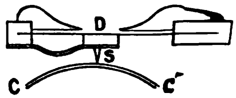

Fig. 244.

NOTE. — The characteristics of sound waves may be studied by means of **sensitive flames.** The peculiarities of different sounds are thus made visible. See Tyndall on Sound, and larger text-books.

QUESTIONS.

1. What is the condition of a sonorous body?

2. Upon what does the intensity of sound depend?

3. Define pitch, quality, resonance, echo, sympathetic vibrations, wave-length, interference, siren, node, overtone.

4. What effect has a rise in temperature upon the velocity of sound in air provided the barometer remains the same?

(*b*) What effect if the barometer falls and the thermometer remains the same? Why?

5. If the tube giving the best resonance for a fork is 13 in. deep, and the temperature of the air is such that the velocity of sound is 1116 ft. per second, what is the vibration-number of the fork?

6. The vibration-number of a fork is 384; what is the depth of its resonance tube, if the temperature of the air is 0°?

7. We hear the whistle of an engine 5 sec. after the jet of steam is seen, and the temperature is $-10°$ C. How far off is the engine?

8. In what three ways may I raise the pitch of a given string one octave?

9. How are pianos "tuned"? (*b*) Closed organ pipes?

10. A string with a tension of 16 lbs. gives E. What tension must be placed upon it to give A?

11. What is the difference between overtones and harmonics? (*b*) What is meant by playing in harmonics?

12. When the wind is blowing against the sound waves produced by a bell, why can one on the top of a tower sometimes hear the bell distinctly, while one at the bottom cannot hear it at all?

13. Why is the pitch of the bell of an approaching engine higher, and that of a departing engine lower, than the tone when the engine is standing still? [Compare approaching and receding stars under spectroscope.]

14. Why does the listener at one end of a long pipe hear *two* blows when only one is struck at the other end?

15. The report of a gun returns to the gunner in $2\frac{1}{2}$ seconds, how far off is the reflecting surface, provided the temperature is 0°?

16. If lycopodium powder is sprinkled over the inside of a long glass tube, and the tube be made to resound by blowing into one end of it through a whistle, why does the powder gather into heaps along the tube?

17. What are Helmholtz's resonators used for?

18. In what one or more of *three* ways do the vocal chords of a bass singer differ from those of a tenor singer?

19. Give a good substitute experiment in place of one used in this chapter.

20. This chapter on Sound might have followed the chapter on the Pendulum. Can you think of any reason for placing Sound after Electricity? (*b*) For placing Sound after Light? (*c*) For placing Light after Sound?

APPENDIX.

SECTION I.

TOOLS, APPARATUS, ETC.

1. Among the tools and apparatus most needful may be enumerated a good knife, hammer, large and small screw-driver, fine-toothed saw, key-saw, flat, triangular, and rat-tail files, miter-box, a square, pair of pincers with cutting edges combined, pair of scissors, gimlets, bitstock and bits, set of awls with stock, half-inch and quarter-inch chisels, vise, a pair of compasses, calipers, small grindstone, small turning-lathe with tools, small emery wheel, soldering kit, a steel glass-cutter, a brass protractor, a bottle of liquid glue, etc.

2. For the more expensive apparatus may be mentioned (with approximate cost) an air pump, $25; a pair of scales with two sets of weights, 1 mm. to 1 kg., and 1 gr. to 1 lb., $25; a Toepler-Holtz or a Wimshurst machine, $35; a dynamo, $45; and a spectroscope with a scale attachment, $40.

3. Cheap apparatus is easily obtained by visiting the grocer's, tin-smith's, plumber's, locksmith's, glazier's, hardware merchant's, brass works, junk shops, etc. This in[illegible]p-chimneys, broken glass for the sides of tanks,

14. W
blows when o

and for other apparatus whose inside must be seen, screw-eyes for "leveling screws" and for innumerable other uses, copper rivets with washers for "binding posts," brass screws, copper tacks, iron screws, nails, brads, double-pointed tacks, bullets, short brass rods, etc. Dealers are often more than willing to give such things for the benefit of the school, especially in the smaller towns.

4. For cutting holes in rubber corks, hollow tubes of brass or iron, sharpened inside at one end with a rat-tail file, may be used. Often one-half of the cork answers the purpose, and saves much work in boring. Two tubes of different sizes will be handy for cutting leather washers.

5. Round hollow brass buttons are excellent for knobs on frictional apparatus.

6. In boring glass, pieces of small rat-tail files set in the lathe will do well. These should be wet with turpentine, and occasionally a bit should be broken off the boring end. Glass may be bored very rapidly in this way, a larger file being used after the hole is through.

7. To cut a glass tube, break the surface on one side with a three-cornered file, and, placing the two thumb-nails precisely opposite, break. Before running these cut tubes through corks or into rubber tubes, fuse them slightly at the ends to prevent their cutting the cork or tube. In bending a long glass tube heat some three inches, at least, of its length.

8. Before putting hot sealing-wax on glass warm the glass slightly.

9. To prevent temporary leakage of air through sealing-wax into a partial vacuum, vaseline or paraffine the wax. For such vessels, however, cement of the right hardness

should be used, and for permanent unions generally cement is to be preferred.

10. Very delicate dynamometers may be made by coiling fine spring brass wire and setting the coil into a frame with a pointer attached. Care must be taken not to strain the spring beyond its limit of elasticity. A dynamometer may be made roughly self-registering when used horizontally by carefully adjusting a very light strip of wood moved by the pointer.

11. Other freezing mixtures, as sodium phosphate (9 parts) and dilute nitric acid (1 part) may be used. These may be found more convenient in summer in a very few places where the ice man is farther away than the druggist. For the composition of other freezing mixtures see the cyclopedia. Salt and ice properly mixed, and in quantity, give a temperature of — 22°, but of course the pupil will fail to get so low a temperature.

12. To make soft iron, keep iron red hot for some time in charcoal coals, and, removing, cool slowly. To harden iron or steel, heat to the red heat and plunge suddenly into cold water.

13. In diluting sulphuric acid pour the acid into the water and not the water into the acid. In the later case the layer of water next to the heavier acid gets heated and may produce a bad spattering of the acid and water. Dilute in a porcelain or annealed glass dish. This will stand the heat developed.

14. Raw silk threads from a cocoon are best for suspending a needle. A jeweled needle from a small compass is excellent for a galvanometer needle. It is better to pivot than to suspend the needle for this purpose. A pivoted needle does not get out of order so easily.

15. A current reverser is easily made by arranging two switches, *S* and *S′*, as shown in Fig. 245, between two sets of binding posts, *AB* and *CD*. The dotted connector (a flat strip of black walnut), moving between two stops, turns both switches at the same time and prevents short circuiting. By moving the strip but half way between the stops, the circuit is broken. When used in connection with a low resistance galvanometer, the wires connecting the binding posts should be very coarse. Brass tacks with broad heads answer well for switch-points, and brass screws or binding posts with double copper washers hold well the lever of the switch. In all accurate work the current should be reversed through galvanometers, and the average deflection taken. Gravity cells, when not in use, should be kept closed through a high resistance coil of fine German silver wire (500 ohms).

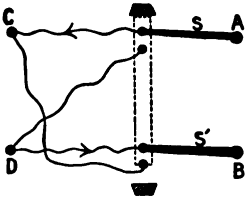

Fig. 245.

16. To darken the room, arrange a curtain of black cloth, *A*, Fig. 246, outside the ordinary curtain, *B*, wider (by six inches on each side) than the window, and sliding in wooden pockets, *CC*, *surrounding* the window, the pockets being painted black inside. This makes an exceedingly convenient method of darkening the room at will. Excellent concave and convex mirrors may be made from watch crystals by covering on the convex side for concave mirrors (and *vice versâ*) with soft tin foil coated with mercury. The glass must have been previously well cleaned and warmed. The mirrors should then be well dried, and mounted in wooden frames.

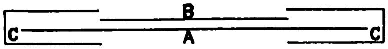

Fig. 246.

Cheap "magnifying lenses" (convex) are easily obtained from the dealers, either mounted or unmounted, or from photographers. The eye-piece of the opera-glass is a concave lens. Glasses for the near-sighted are also concave.

17. The frontispiece, of course, represents the spectra only approximately. Bands of light without distinct lines appear in nearly all. This is especially noticed in the potassium.

18. In Fig. 188 the arrows are arranged to show the direction of the current *when the apparatus is used as a motor.* The same is true of the + and − poles of the soft iron core of the armature. When used as a dynamo, the current in the armature during the movement through the first quarter *tends* to make the upper pole positive, while the field magnet tends to make it negative.

SECTION II.

MENSURATION RULES.

D = diameter, C = circumference, and R = radius ; h = altitude.

1. $\pi = 3.1416$.
2. $C = \pi D$.
3. Area of triangle = base $\times \frac{1}{2} h$.
4. Area of circle = $\frac{1}{4} \pi D^2$ or πR^2.
5. Area of ellipse = product of axes $\times \frac{1}{4} \pi$.
6. Surface of sphere = πD^2 or $4 \pi R^2$.
7. Volume of sphere = $\frac{1}{6} \pi D^3$.
8. Volume of pyramid or cone = area of base $\times \frac{1}{3} h$.
9. Volume of a cylinder = area of base $\times h$.
10. Volume of material forming hollow cylinder = difference of areas of basal circles $\times h$.

11. Volume of the frustum of a pyramid or cone $= \frac{1}{3} h \times$ [area one base + area other base + the square root of the product of the two areas].

NOTE. — The area of a circle whose diameter is 1 is $\frac{1}{4}$ of π (.7854). The volume of a sphere whose diameter is 1 is $\frac{1}{6}$ of π (.5235).

SECTION III.

RELATIVE DENSITIES (Sp. Gr.).

SOLIDS.

Aluminum	2.67	Iron (bar)	7.79
Beeswax	.96	Iron (cast)	7.23
Brass (cast)	8.38	Lead (cast)	11.36
Cedar	.55	Magnesium	1.75
Cork (air driven from pores)	.24	Oak, white	.78
Copper (sheet)	8.89	Pine, yellow	.46
Diamond	3.53	Platinum	22.06
Glass (crown)	2.52	Potassium	.86
Glycerine	1.26	Silver (cast)	10.47
Gold	19.36	Sulphur, native	2.03
Human body	.89	Tin (cast)	7.29
Ice	.92	Zinc (cast)	7.

LIQUIDS.

Alcohol, absolute	.80	Mercury	13.59
Alcohol, common	.83	Milk	1.03
Carbon, bisulphide	1.29	Olive Oil	.91
Chloroform	1.53	Sulphuric Acid	1.84
Ether	.72	**Water**, distilled, 4°	**1.00**

NOTE. — Different specimens of the same material will vary slightly in density. All tables are more or less approximate.

GASES.

Standard: air at 0° C.; *barometer at* 760 *mm.*

Air	**1.00**	Hydrogen	.069
Carbon dioxide	1.53	Nitrogen	.971
Chlorine	2.45	Oxygen	1.105

SECTION IV.

NORMAL MELTING POINTS.

Alcohol	− 130° C.	Platinum	1775° to 2000°
Beeswax	62.	Potassium	62.5
Brass	1020.	Saturated Solution NaCl	− 22.
Butter	33.	Silver	1000.
Fusible Metal	91° and upward	Sulphur	115.
Gold	1250.	Tallow (fresh)	43.
Ice	**0.**	Tin	235.
Iron	1500 to 1600.	Turpentine	− 27.
Lead	334.	Zinc	433.
Mercury	− 39.5		

NOTE. — The solidifying point is the same as the melting point, i.e., they are so nearly alike that we have no means of measuring the difference between them. If freed from air and kept very still, water may be cooled far below its *normal* freezing point before solidifying. At the slightest disturbance such water at once solidifies with a rapid rise in temperature to 0°. Pressure also affects the melting or solidifying points.

SECTION V.

SPECIFIC HEATS.

SOLIDS.		LIQUIDS.		GASES.[1]	
Aluminum	.212	Alcohol	.597	Air	.237
Bismuth	.029	Lead (melted)	.040	Chlorine	.121
Brass	.085	Mercury	.033	Steam	.481
Copper	.093	Turpentine	.432		
Ice	.504	**Water**	**1.000**		
Lead	.031				

NOTE. — For the purpose of the solution of problems more readily, the specific heats of ice and steam may be taken as .5.

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[1] With pressure constant.

SECTION VI.

NORMAL BOILING POINTS (Barometer 760 mm.).

Alcohol	78°. 4 C.	**Water**, distilled	**100.°**
Ether	34.9	Saturated solution Na Cl	102.
Mercury	350.	Saturated solution KNO_3	116.
Sulphur	448.4	Saturated solution $Ca\,Cl_2$	179.
Sulphur dioxide	− 8.		

NOTE. — Water, if freed from air and kept very quiet, may be raised far above its normal boiling point without ebullition. If disturbed, it is then likely to boil with explosive violence. The nature of the material of which the containing vessel is made, and other causes not mentioned in this book, influence slightly the boiling point.

SECTION VII.

LATENT HEAT OF LIQUEFACTION AND VAPORIZATION.

LIQUEFACTION.

Beeswax	97.2	Sulphur	9.4
Lead	5.4	Tin	14.3
Platinum	27.2	**Water**	**80.0**
Potassium nitrate	47.4	Zinc	28.1

VAPORIZATION.

Alcohol	202.4	Turpentine	74.
Ether	90.4	Water	537.[1]
Mercury	62.		

SECTION VIII.

COEFFICIENTS OF EXPANSION.

LINEAR.

Aluminum	.0000222	Lead	279
Brass (ciphers omitted)	188	Platinum	086
Copper	187	Silver	194
Glass	086	Steel, tempered	132
Iron (cast)	113		

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[1] According to Andrews, 535.9.

CUBICAL.

Gases	.003667	Mercury	0181
Alcohol (ciphers omitted)	1080	Turpentine	1050
Glass	0025	Water (4° to 100°)	0449

SECTION IX.

CONDUCTIVITY FOR HEAT.

Bismuth	1.8	Lead	8.5
Brass, polished	33.	Platinum	8.4
Copper	77.6	Silver, polished	100.
Iron	11.9		

SECTION X.

NATURAL TANGENTS.

DEG.	TANG.	DEG.	TANG.	DEG.	TANG.	DEG.	TANG.	DEG.	TANG.	DEG.	TANG.
1	.017	16	.287	31	.601	46	1.036	61	1.80	76	4.01
2	.035	17	.306	32	.625	47	1.07	62	1.88	77	4.33
3	.052	18	.325	33	.649	48	1.11	63	1.96	78	4.70
4	.070	19	.344	34	.675	49	1.15	64	2.05	79	5.14
5	.087	20	.364	35	.700	50	1.19	65	2.14	80	5.67
6	.105	21	.384	36	.727	51	1.23	66	2.25	81	6.31
7	.123	22	.404	37	.754	52	1.28	67	2.36	82	7.12
8	.141	23	.424	38	.781	53	1.33	68	2.48	83	8.14
9	.158	24	.445	39	.810	54	1.38	69	2.61	84	9.51
10	.176	25	.466	40	.839	55	1.43	70	2.75	85	11.43
11	.194	26	.488	41	.869	56	1.48	71	2.90	86	14.30
12	.213	27	.510	42	.900	57	1.54	72	3.08	87	19.08
13	.231	28	.532	43	.933	58	1.60	73	3.27	88	28.64
14	.249	29	.554	44	.966	59	1.66	74	3.49	89	57.29
15	.268	30	.577	45	1.000	60	1.73	75	3.73	90	∞

SECTION XI.

SPECIFIC ELECTRICAL RESISTANCES.

SOLIDS.	SILVER STANDARD.	COPPER STANDARD.	FLUIDS.	SILVER STANDARD MILLIONS.
Silver	1.00	.94	Nitric acid	1.
Copper	1.06	1.00	Sulphuric acid	2.
Zinc	3.74	3.53	Sat. Sol. Na Cl	3.
Brass	3.81	3.59	Sat. Sol. CuSO_4	18.
Platinum	6.02	5.68	Distilled Water	10000.
Iron	6.46	6.09	Glass	15 million.
German Silver	13.91	13.12	Gutta Percha	Much greater
Mercury	63.24	59.66	Dry Air	than the last.

NOTE. — According to the definition of ohm used in this book, it will be much more convenient to use the unusual copper standard for specific resistances in all problem work. These figures may represent ohms for a given length and diameter of wire made of the given material. The resistances in the right-hand column are expressed in millions of ohms. Different specimens of the same alloy vary widely in specific resistance.

SECTION XII.

ABSOLUTE INDICES OF REFRACTION, D LINE.

Air	1.000294	Glycerine	1.47
Alcohol	1.36	Ice	1.31
Carbon bisulphide . .	1.63	Iceland spar (ordinary) .	1.65
Crown glass	1.52	Iceland spar (extra. ray) .	1.48
Diamond	2.65	Selenium crystals . . .	2.94
Flint glass	1.61	Water	1.33

NOTE. — The relative index of refraction for air into the substance is found by dividing the absolute index (for a vacuum into the substance) by the absolute index for air. This relative index differs, as is easily seen, only slightly from the absolute index, because the absolute index for air exceeds unity by so small an amount.

SECTION XIII.

VELOCITY OF SOUND AT 0° C.

FEET PER SECOND.

Air	1,093	Hydrogen	4,163
Ash (with grain)	15,314	India Rubber	197
Chlorine	677	Iron	17,822
Copper	11,666	Lead	4,030
Glass	16,488	Steel	17,182
Gold	5,717	Water	4,586

SECTION XIV.

MISCELLANEOUS APPROXIMATE EQUIVALENTS.

1 m. = 3.28 ft. = 39.37 in.
1 ft. = 3.048 dcm.
1 in. = 2.54 cm.
1 sq. m. = 1.196 sq. yd.
1 sq. ft. = 9.29 sq. dcm.
1 sq. in. = 6.45 sq. cm.
1 kg. = 2.2 lbs. Av.
1 lb. = $\frac{5}{11}$ kg.
1 cu. m. = 1.308 cu. yd.
1 cu. ft. = 28.32 cu. dcm.
1 cu. in. = 16.39 cu. cm.
1 cu. cm. = .061 cu. in.
1 liter (1 cu. dcm.) = 1.057 liquid quarts.
1 liter = .908 dry quarts.
1 gallon = 3.785 liters = 231 cu. in.
1 liter = 61.027 cu. in.

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